NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION

NETHERLANDS SHIP MODEL BASIN

WAGENINGEN
NEDERLAND

RESEARCH ON THE "NOZZLE + SCREW" PROPELLER

Contract No. DA - 91 - 591 - EUC - 1659 - OI - 7317 - 61.

NETHERLANDS SHIP MODEL BASIN

HAAGSTEEG 2 - WAGENINGEN - NETHERLANDS

Final Technical Report

Research on the "Nozzle + Screw" Propeller

(Ducted Propellers)

Contract No. DA - 91 - 591 - EUC - 1659
OI - 7317 - 61

Period covered by the report:

From January 1, 1961 through October 31, 1962

The research reported in this document has been made possible through the support and sponsorship of the U.S. Department of Army, through its European Research Office.

M.

Introduction.

Open water tests and cavitation tests were carried out in order to investigate the influence of the propeller load at the tip and the clearance between blade tip and nozzle on efficiency, cavitation and noise.

These tests are a continuation of the tests described in ref [1].

1. Data of the examined "screw + nozzle" propellers.

The screw models 2978 through 2981 were tested in nozzle no. 19 (see ref. [1]). The characteristics of these models are given in the table I, further details in the figures 1 through 4.

The diameters of the screw models were reduced step by step in order to obtain different tip clearances. The inner diameter of the nozzle model remained unaltered.

Clearances of 1, 1.5, 2.0, 2.5 and 3.0 mm were realized.

TABLE I

Screw no.	2978	2979	2980	2981
Diameter (mm)	240.00	240.00	240.00	240.00
Number of blades	4	4	4	4
Pitch at root (mm)	253.10	240.00	213.70	200.00
Pitch at blade tip (mm)	219.84	240.00	280.32	300.48
Pitch at 0.7 R (mm)	240.00	240.00	240.00	240.00
B.A.R.	0.55	0.55	0.55	0.55

The pitch distribution of screw 2980 is calculated according to ref. [2] , however with a slightly modified distribution of the pressure difference Δ p created by the screw in the nozzle, i.e. with

$$\frac{\Delta p}{\Delta P \text{ mean}} = (4.88 - 4x)\,(x - 0.133)$$

The pitch of screw 2979 is taken uniform.

The pitch increase from 0.7 R to the blade tip of screw 2981 is 1.5 that of screw 2980.

The decrease in pitch from 0.7 R to the blade tip of screw 2978 is taken half the pitch increase of screw 2980.

2. Tests carried out and their results.

2.1. Open water tests.

The open water tests have been carried out at 10 rps of the screw models and speeds of advance covering a slip range from 0 to 100 %. The submersion of the propeller shaft was 240 mm, resulting in a cavitation number.

$$\sigma_n = \frac{p_o - e}{\rho/2\,(nd)^2} \approx 34.5$$

The K_T, K_Q, η_p and J values were all calculated with the diameter of the original screws, (tip clearance 1 mm)

The results of the open water tests with the original screw models (tip clearance 1 mm) are given in figure no. 5 (see also figure 3 in ref. [1]).

The percentages drop in efficiency due to the larger tip clearances are plotted in figure 6 on basis of blade tip clearance.

2.2. Cavitation tests.

The tests to investigate the influence of tip load and tip clearance on efficiency, on cavitation and on noise at various cavitation numbers, have been carried out in cavitation tunnel I with a 0.90 m x 0.90 m closed test section and a uniform flow.

The tests were carried out at 30 rps of the screw models, at water speeds in the test section ranging from about v_{et} = 1,75 m sec^{-1} to 6.2 m sec^{-1} and at five cavitation numbers $\sigma_n = \frac{p_o - e}{\rho/2\,(nd)^2}$, viz. σ_n = 2.90 ; 3.35 ; 4.0 ; 5.0 and 6.0.

These cavitation numbers have been chosen within a range of pressures in the test section of the tunnel (7670 kg m^{-2} to 15860 kg m^{-2}) at which the influence of the relative air content α/α_s *) is almost constant at the screw rpm and water speeds concerned ($0.20 < \alpha/\alpha_s < 0.65$).

The torque and thrust on the screw and the thrust on the nozzle model were measured by means of strain gauges.

In fig. 7 through 10 the K_T, K_Q and η_p curves are given on a basis of the advance coefficient J for the cavitation number $\sigma_n = 2.90$.

The influence of the cavitation number and tip clearance on performance is shown in the figures 11 and 12.

Fig. 13 shows the relation between blade tip clearance and efficiency loss at $\sigma_n = 2.90$.

Cavitation observations were made during all tests. The diagrams fig. 14 and 15, show the inception lines for back face- and tip vortex cavitation in dependence on cavitation number and advance coefficient.

Back cavitation was observed beginning at 1.0 R and spreading down the leading edge and developing over the blade at decreasing σ_n and J (for all clearances). Compared at the same σ_n and J the smallest extent of the the sheet cavitation on back is on screw 2978 and it increases in the order of the screws 2978 through 2981.

Face cavitation was observed at the leading edge, increasing in extent at decreasing σ_n and increasing J for all clearances. A brief description of this phenomenon on the various screws is given on page 5.

*) see list of symbols.

Screw 2978: beginning at 1.0 R and gradually spreading down the leading edge.

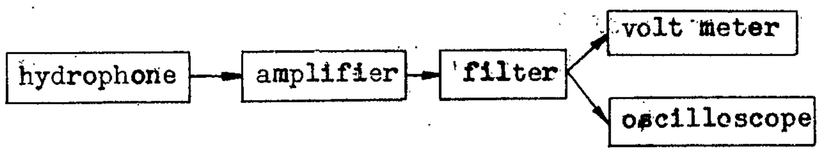
Screw 2979: beginning at 1.0 R and more rapidly spreading down the leading edge.

Screw 2980: beginning between 0.8 R and 1.0 R and rapidly spreading down the leading edge at decreasing σ_n.

Screw 2981: beginning between about 0.5 R and 0.7 R and extending rapidly to 1.0 R and gradually further down the leading edge at decreasing σ_n.

The cavitation phenomena at the design point are given in the sketches fig. 16 through 19 for 1, 2 and 3 mm clearance.

The arrangement of the measuring device for the sound pressure level (SPL) is given in the block diagram below



The hydrophone was mounted in the tunnel wall 0.50 m downstream of the screw.

The measurements were carried out in the 8-16 kcs octave, in which band differences in the (high frequency) cavitation noise are the best perceptible.

The SPL's given in the diagrams fig. 20 through 27, are relative values and include propeller noise and back ground noise.

The SPL of the back ground noise is given in table II.

TABLE II

SPL of back ground noise in dB						
σ_n \ J	0.245	0.42	0.55	0.65	0.75	0.85
2.90	15	15	13	11.5	14/14.5	19/25
3.35	15	15	13	12	14	15.5/18
4.00	15.5	15	13.5	12.5	14	15.5
5.00	15.5	15.5	13.5	13	14.5	15.5
6.00	16	15.5	14	13.5	15	15.5

Fig. 20 through 23 present the measured total SPL's for the various cavitation numbers σ_n on a basis of advance coefficient J, separately for the different clearances.

3. Discussion on the results.

In order to enable a sound comparison to be made between the performance of the various screw + nozzle combinations the results should be compared for the same design requirements, as for example a certain thrust at a specified number of rpm, having in mind that each combination should serve for the same ship; so for a given thrust-speed relationship. The comparisons as to the influence of radial tip load and clearance on efficiency, cavitation and noise are based on equal thrust or equal C_T value (the screw diameter is taken constant and the thrust speed relationship is given). In order to meet for each combination the requirement of a given thrust at a specified number of rpm some some pitch corrections will be necessary.

It is expected however that these corrections will have no appreciable effect on the efficiency, the cavitation phenomena and the noise, sothat the comparisons made on basis of equal thrust development (equal C_T) are considered to be sound as well.

The comparison of the four screws is restricted to the thrust coefficients, $C_T = 10$ and $C_T = 1.5$, these C_T values being the limiting values of the operating range of a screw + nozzle system.

A. Open water test results.

A.1. Influence of radial tip load on efficiency.

In table III the efficiencies at $C_T = 10$ and $C_T = 1.5$ are given for the four screws and various clearances.

TABLE III

Open water efficiencies						
Screw no.	2978			2979		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	.440	.431	.424	.446	.437	.430
$C_T = 1.5$	.612	.608	.604	.625	.614	.603

TABLE III (continued)

Open water efficiencies						
Screw no.	2980			2981		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	.452	.441	.432	.447	.438	.430
$C_T = 1.5$	.635	.620	.610	.625	.612	.603

This table shows that for equal clearances the radial load distribution has not a large effect on the efficiency.

A.2. Influence of the blade tip clearance on efficiency.

Fig. 6 and table III show that the efficiency decreases with increasing blade tip clearance for all screws. The percentage drop in efficiency is about the same at $C_T = 10$ and at $C_T = 1.5$ for screw 2981, but for screw 2978 the drop at $C_T = 10$ is larger than at $C_T = 1.5$.

B. Cavitation tunnel test results.

B.1. Influence of cavitation number on performance.

The figures 11 and 12 show that within the range of investigated cavitation numbers, the influence of σ_n on performance may be neglected. For each combination K_{Ttot} and η_p remain constant for various σ_n at constant J, hence K_T and η_p remain also constant for various σ_n at constant C_T. Thus an increase of σ_n from 2,90 to 6.0 (i.e. when running the screws from full to half the full power rpm) has no influence on efficiency. Therefore the below mentioned comparisons with respect to efficiency are only given for $\sigma_n = 2,90$.

B.2. Influence of radial tip load on efficiency.

In table IV the efficiencies at $C_T = 10$ and $C_T = 1.5$ are given for the four screws and various clearances.

TABLE IV

Efficiencies from cavitation tunnel tests						
Screw no.	2978			2979		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	.428	.430	.435	.439	.431	.432
$C_T = 1.5$	.560	.577	.598	.580	.582	.597

TABLE IV (continued)

Efficiencies from cavitation tunnel tests						
Screw no.	2980			2981		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	.452	.444	.438	.468	.453	.440
$C_T = 1.5$	.625	.619	.610	.624	.618	.605

It appears that for 1 and 2 mm clearance the efficiency increases with increasing radial tip load ; for 3 mm clearance the effect of radial tip load on efficiency is small.

B.3. <u>Influence of blade tip clearance on efficiency.</u>

Fig. 13 and table IV show that:

a. $\frac{\partial \eta_p}{\partial btc} < 0$ for screw 2981 ; the efficiency at increasing blade tip clearance (btc) decreases more for $C_T = 10$ than for $C_T = 1.5$.

b. The same occurs for screw 2980, though $\frac{\partial \eta_p}{\partial btc}$ is less negative than for screw 2981.

c. For screw 2979 the efficiency drops at first at a small increase of the clearance ; increasing the clearance further leads to an increase of the efficiency.

d. $\frac{\partial \eta_p}{\partial btc} > 0$ for screw 2978 where for $C_T = 10$ the efficiency at increasing clearance increases less than for $C_T = 1.5$.

B.4. <u>Influence of radial tip load, cavitation number and C_T on cavitation.</u>

The observations and the fig. 14 and 15 show that for all clearances,

a. for constant C_T the inception of cavitation shifts to higher σ_n values at increasing tip load (in the order of the screws 2978 through 2981). The extent of cavitation increases of course at decreasing σ_n and increasing C_T.

b. for $C_T = 1.5$ the screws 2978 and 2979 are cavitation free over the range of investigated cavitation numbers.

c. for $C_T = 10$ screw 2978 is cavitation free at $\sigma_n >$ about 5.0, screw 2979 at $\sigma_n >$ about 5.5.

d. screws 2980 and 2981 have back cavitation for $C_T = 10$ as well as for $C_T = 1.5$, whereas screw 2981 has a beginning of face cavitation at the lowest σ_n and C_T.

B.5. <u>Influence of blade tip clearance on cavitation.</u>

The fig. 14 through 19 show that at all investigated cavitation numbers and for all screws.

a. the extent of cavitation increases slightly if the blade tip clearance becomes larger.

b. the inception of back, face and tip vortex cavitation is shifted to higher J values at increasing blade tip clearance (only the results of the screws 2980 and 2981 with 2 mm clearance deviate from this trend).

So it can be concluded that the point of shock free entry shifts to higher J values, i.e. the induced angles of attack are slightly reduced at increasing blade tip clearance.

B.6. Influence of back ground noise on the measured SPL.

The variations in the measured noise levels (including back ground noise) as given in fig. 20 through 23, are caused by the propeller itself for J up to 0.75, because in the lower region the back ground noise is constant (table II).

At higher advance ratios and for cavitation numbers $\sigma_n < 4.0$ the back ground noise has increased very much.

B.7. Influence of propeller load C_T and cavitation number σ_n on the noise.

In tables V and VI the SPL of the four screws is given at $C_T = 10$ and $C_T = 1.5$ resp. for $\sigma_n = 2.9$ and for $\sigma_n = 6.0$.

TABLE V

Relative noise level for $\sigma_n = 2.9$						
Screw no.	2978			2979		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	31	27½	25	31½	27½	27½
$C_T = 1.5$	29½	24	25	27	24½	24

TABLE V (continued)

Relative noise level for $\sigma_n = 2.9$						
Screw no.	2980			2981		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	35	29½	22	36½	33½	29
$C_T = 1.5$	28½	29	26	31½	30	28

TABLE VI

Relative noise level for $\sigma_n = 6.0$						
Screw no.	2978			2979		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	24	22	23	19	$24\frac{1}{2}$	26
$C_T = 1.5$	$19\frac{1}{2}$	19	18	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$

TABLE VI (continued)

Relative noise level for $\sigma_n = 6.0$						
Screw no.	2980			2981		
Clearance in mm	1	2	3	1	2	3
$C_T = 10$	34	$33\frac{1}{2}$	$33\frac{1}{2}$	34	$34\frac{1}{2}$	35
$C_T = 1.5$	25	25	$24\frac{1}{2}$	27	27	$26\frac{1}{2}$

These tables and fig. 20 through 23 show that:

a. all SPL's are lowest in the range $0.6 < J < 0.7$ which coincides with the range of shock free entry of the screws (see fig. 14).

b. the SPL increasesat decreasing J (increasing C_T ; $J < 0.6$) due to the inception of back and tip vortex cavitation, and also at $J > 0.7$ due to the inception of cavitation on face and partly due to increased background noise.

c. for the screws 2978 and 2979 with 1 mm clearance the SPL decreases appreciably at increasing σ_n for both C_T values i.e. $\frac{\partial SPL}{\partial \sigma_n} < 0$
This gradient becomes less negative, if the clearance is larger.

d. for the screws 2980 and 2981 with 1 mm clearance also $\frac{\partial SPL}{\partial \sigma_n} < 0$ at $C_T = 1.5$, but $\frac{\partial SPL}{\partial \sigma_n} \approx 0$ at $C_T = 10$.
This gradient becomes again resp. less negative, and even positive for the larger clearance.

B.8. Influence of the radial tip load on noise production.

From the table V and VI it appears that in general the noise level increases with radial tip load which increase is the most pronounced at $C_T = 10$ and $\sigma_n = 6.0$.

B.9. Influence of the blade tip clearance on noise production.

The figs. 24 through 27 present the SPL of the four screws for constant values of C_T and various σ_n on a basis of blade tip clearance (btc).

From these figures as well as from the tables V and VI it appears that for all screws

a. for $\sigma_n = 2.9$ the SPL decreases at increasing clearance
b. for $\sigma_n = 6.0$ the SPL is hardly affected by the clearance.

4. Conclusions.

A. Efficiency.

1. Screw 2980 with high radial tip load and with 1 mm clearance between screw and nozzle, gives the best results in open water, although the differences with the other screws are small.
2. Screw 2981 with the highest radial tip load and with 1 mm clearance is the best in the cavitation tunnel for $2.9 < \sigma_n < 6.0$ (however the difference with screw 2980 at $C_T = 1.5$ is nil).
   Screw 2978 with the lowest radial tip load has the lowest efficiency.
   With 1 mm clearance screw 2981 gives an appreciably higher efficiency than screw 2978. This difference in efficiency becomes very small with 3 mm clearance.

B. Cavitation.

Screw 2978 with the lowest radial tip load gives the best results.

C. Noise.

The screws 2978 and 2979 (with uniform pitch) and with 3 mm clearance give the lowest SPL, the difference in SPL of these screws however being small.

Screw 2981 with the highest radial tip load gives the highest SPL.

Taking into account the effect of the blade tip clearance, which shows that within the operating range:

a. the difference in efficiency between the screws becomes smaller at increasing clearance
b. the noise level decreases in general with increasing clearance.

It may be concluded that:

a. with 1½ mm clearance the choice of radial load distribution for the screw depends on which property is the most important, i.e. efficiency, cavitation or noise.
b. with 3 mm clearance the screws with the lowest radial tip load are to be preferred.

Wageningen, January 1963

Prof.Dr.Ir. J.D. van Manen.
Principal Investigator.

REFERENCES:

ref. 1 Final Technical Report - Contract no. DA - 91 - 591 - EUC - 1294. OI - 4151 - 60.

ref. 2 The design of screw-propellers in nozzles - by J.D. van Manen and A. Superina - Publication no. 137 of the N.S.M.B. - Int. Shipb. Progress Vol. 6 no. 55, 1959.

LIST OF SYMBOLS:

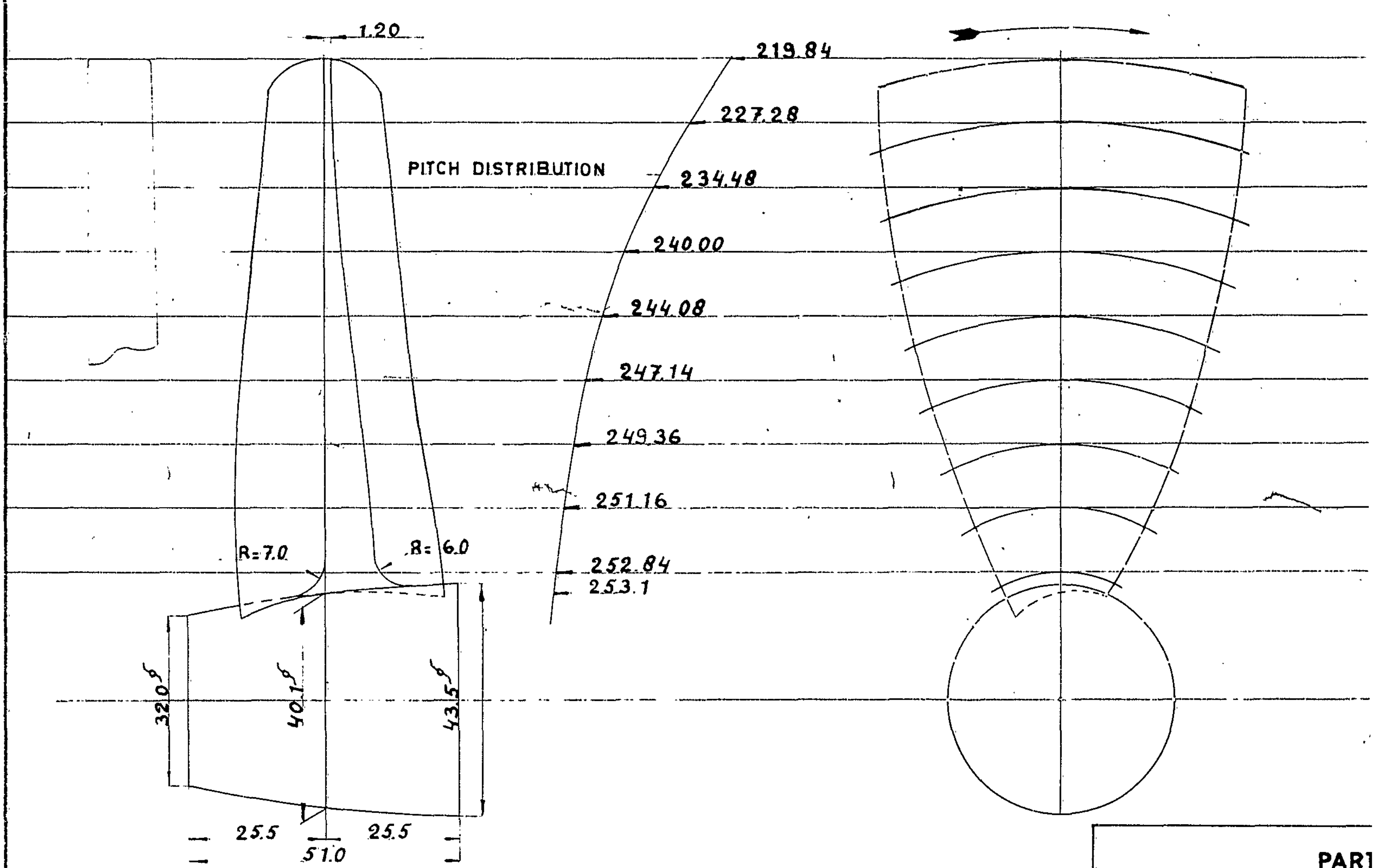
		units
d	= diameter of screw	m
x	= nondimensional screw radius	
n	= number of revs. per sec.	sec^{-1}
v_e	= speed of advance	$m\ sec^{-1}$
J	$= \frac{v_e}{n.d}$ = advance coefficient	
T	= thrust	kg
K_T	$= \frac{T}{\rho d^4 n^2}$ = thrust coefficient	
$K_{T screw}$	= thrust coeff. of screw	
$K_{T nozzle}$	= thrust coeff. of nozzle	
C_T	$= \frac{K_T}{J^2} \frac{8}{\pi}$ = thrust constant	
Q	= torque	kgm
K_Q	$= \frac{Q}{\rho d^5 n^2}$ = torque coefficient	
ρ	= density of water	$kg\ m^{-4}\ sec^2$
η_p	$= \frac{K_T}{K_Q} \frac{J}{2\pi}$ = efficiency	
p_o	= atmospheric + hydrostatic pressure on centre of propeller shaft	kgm^2
e	= vapour pressure	$kg\ m^2$

$\sigma_n = \dfrac{p_o - e}{\rho/2\ n^2 d^2}$ = cavitation number with respect to revs. per sec.

α = amount of disolved + entrained air in the water, measured by the van Slyke method, at a pressure of 760 mm Hg and 0° C. — cm^3 pro ltr.

α_s = saturation amount of air in water — cm^3 pro ltr.

α/α_s = relative air content.



1

PART

DIAMETER	D
NUMBER OF BLADES	Z
PITCH AT ROOT	Hn
PITCH AT BLADE TIP	Ho
PITCH AT 0 7R	H0.7R

2

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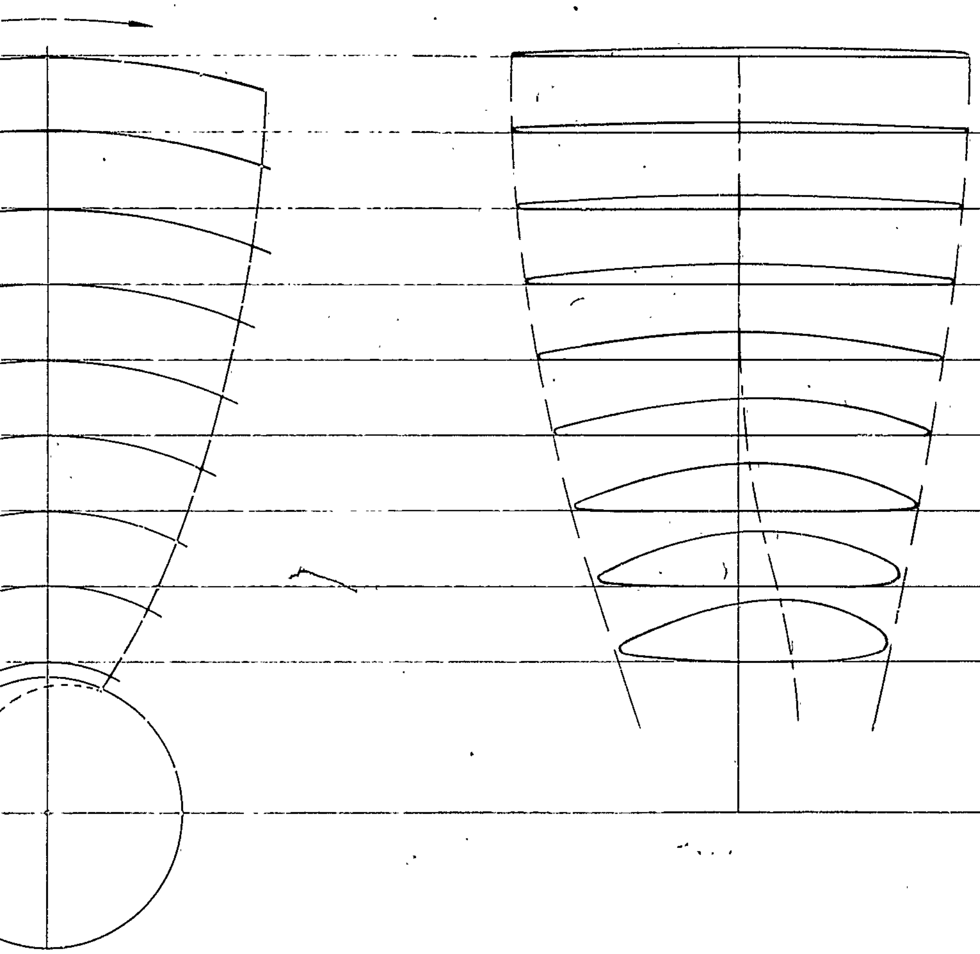


No	RADIUS	MAX. THICKNESS
1.0	120.0	120
0.9	108.0	1.47
0.8	96.0	2.21
0.7	84.0	3.30
0.6	72.0	4.56
0.5	60.0	5.89
0.4	48.0	7.20
0.3	36.0	8.45
0.2	24.0	9.60

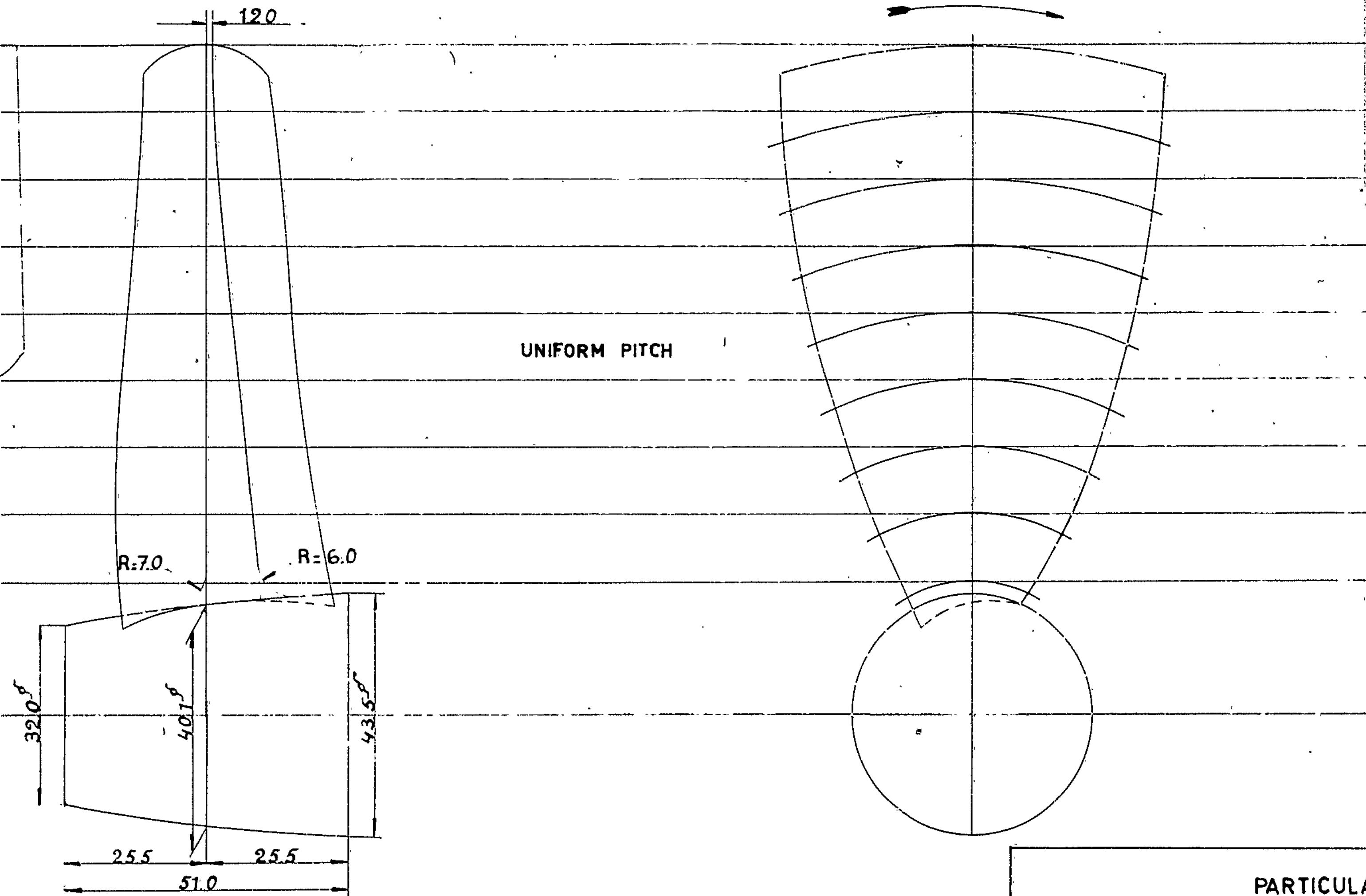
PARTICULARS OF PROPELLER MODEL

DIAMETER	D = 240.00 mm		
NUMBER OF BLADES	Z = 4	HUB DIAMETER RATIO	d_n/d = 0.167
PITCH AT ROOT	Hn = 253.10 mm	PITCH RATIO AT 0.7R	$H_{0.7}/D$ = 1.000
PITCH AT BLADE TIP	Ho = 219.84 mm	B.A.R.	F_a/F = 0.55
PITCH AT 0.7R	H0.7R = 240.00 mm	MATERIAL	BRONZE

PROPELLER MODEL No 2978

DRAWING No S 2978 - 1

FIG. 1



PARTICULA	
DIAMETER	D = 240
NUMBER OF BLADES	Z = 4
PITCH AT ROOT	Hn = 240.
PITCH AT BLADE TIP	Ho = 240.
PITCH AT 0.7 R	H0.7R = 240

1

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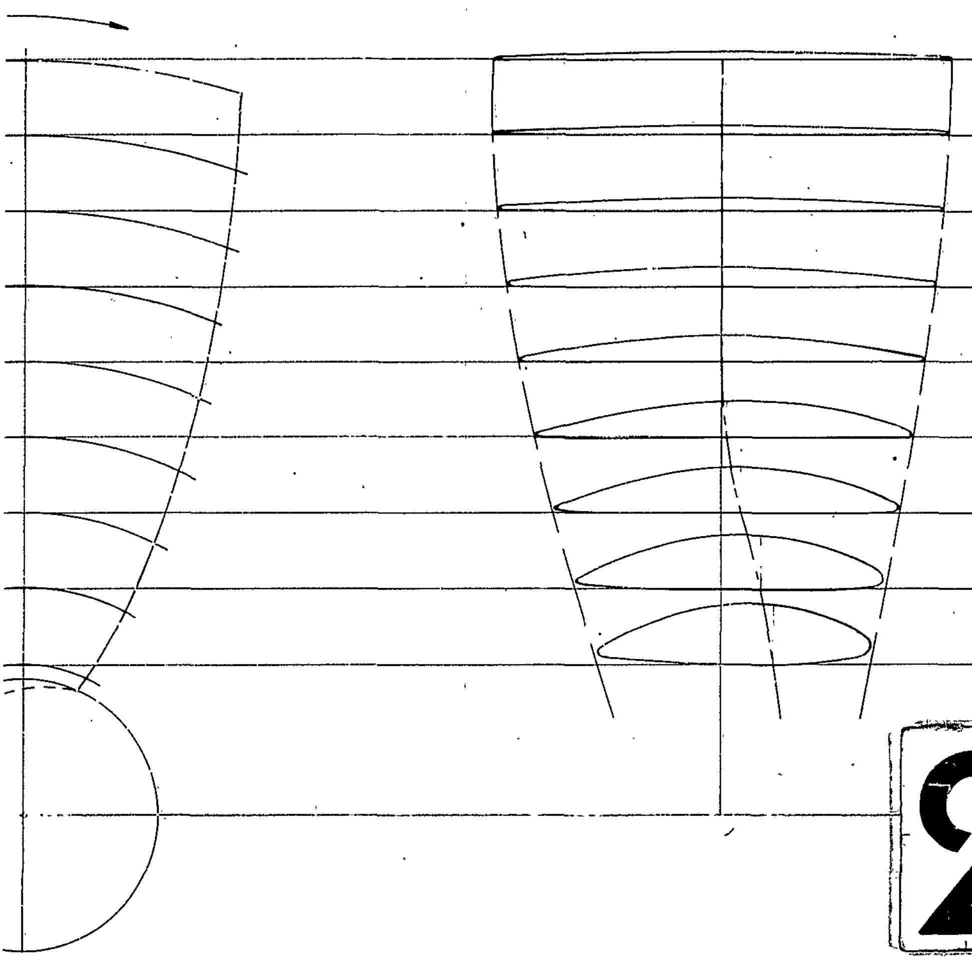

No	RADIUS	MAX. THICKNESS
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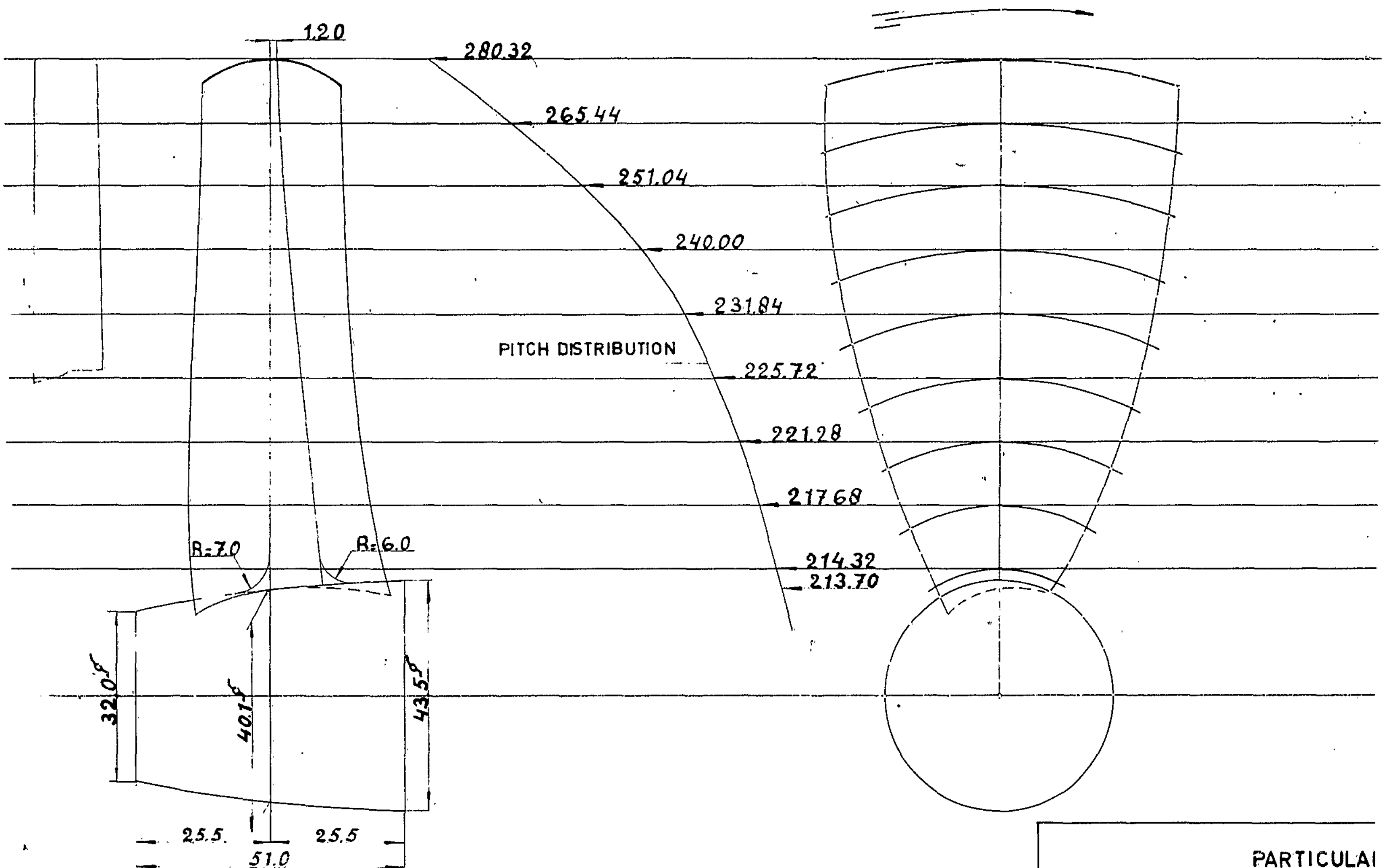
0.5	60.0	5.89
0.4	48.0	7.20
0.3	36.0	8.45
0.2	24.0	9.60

2

PARTICULARS OF PROPELLER MODEL		
DIAMETER D = 240.00mm		PROPELLER MODEL No 2979
NUMBER OF BLADES Z = 4	HUB DIAMETER RATIO dn/d = 0.167	
PITCH AT ROOT Hn = 240.00 mm	PITCH RATIO H/D = 1.000	
PITCH AT BLADE TIP Ho = 240.00 mm	B.A.R. Fa/F = 0.55	DRAWING No S 2979 - 1
PITCH AT 0.7R H0.7R = 240.00mm	MATERIAL BRONZE	

FIG. 2



1

PARTICULAI

DIAMETER	D = 240.
NUMBER OF BLADES	Z = 4
PITCH AT ROOT	Hn = 213.7
PITCH AT BLADE TIP	Ho = 280.
PITCH AT 0.7 R	H0.7R = 240.

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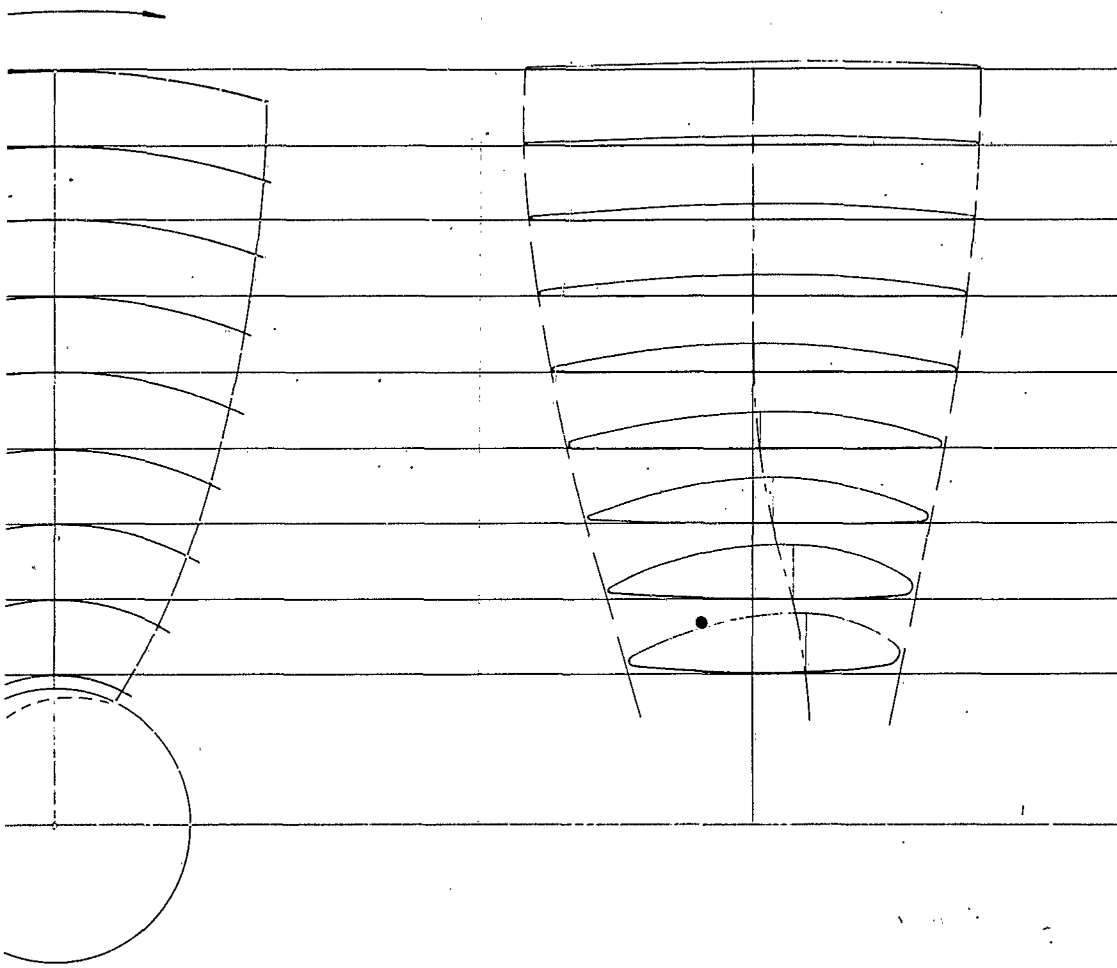


No	RADIUS	MAX. THICKNESS
1.0	120.0	1.20
0.9	108.0	1.47
0.8	96.0	2.21
0.7	84.0	3.30
0.6	72.0	4.56
0.5	60.0	5.89
0.4	48.0	7.20
0.3	36.0	8.45
0.2	24.0	9.60

PARTICULARS OF PROPELLER MODEL

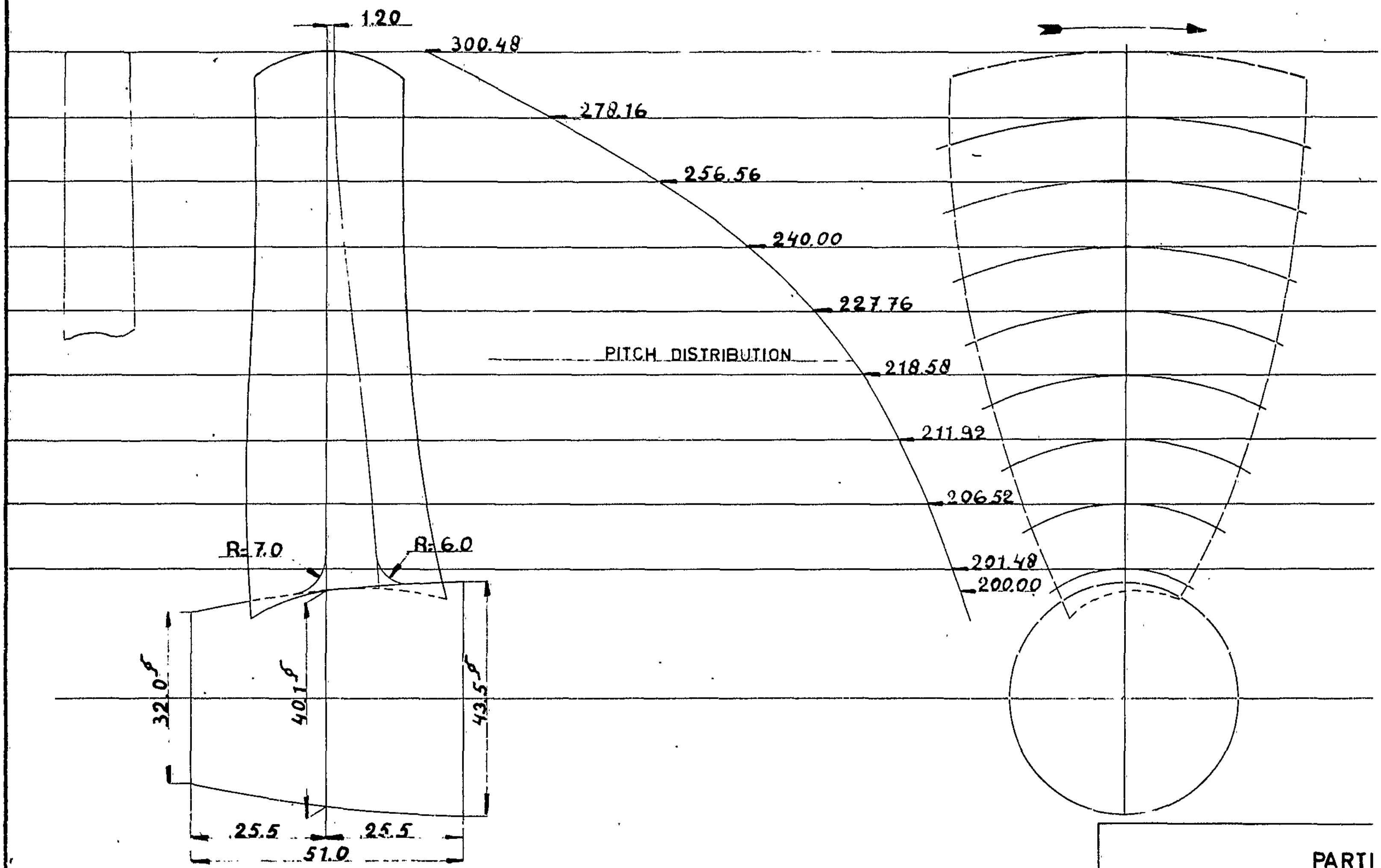
DIAMETER	$D = 240.00$ mm
NUMBER OF BLADES	$Z = 4$
PITCH AT ROOT	$H_n = 213.70$ mm
PITCH AT BLADE TIP	$H_o = 280.32$ mm
PITCH AT 0.7 R	$H_{0.7R} = 240.00$ mm
HUB DIAMETER RATIO	$d_n/d = 0.167$
PITCH RATIO AT 0.7 R	$H_{0.7}/D = 1.000$
B.A.R.	$F_a/F = 0.55$
MATERIAL	BRONZE

PROPELLER MODEL No 2980

DRAWING No S 2980 - 1

2

FIG. 3



1

PARTI

DIAMETER	[
NUMBER OF BLADES	Z
PITCH AT ROOT	Hr
PITCH AT BLADE TIP	Ho
PITCH AT 0.7 R	H0.7F

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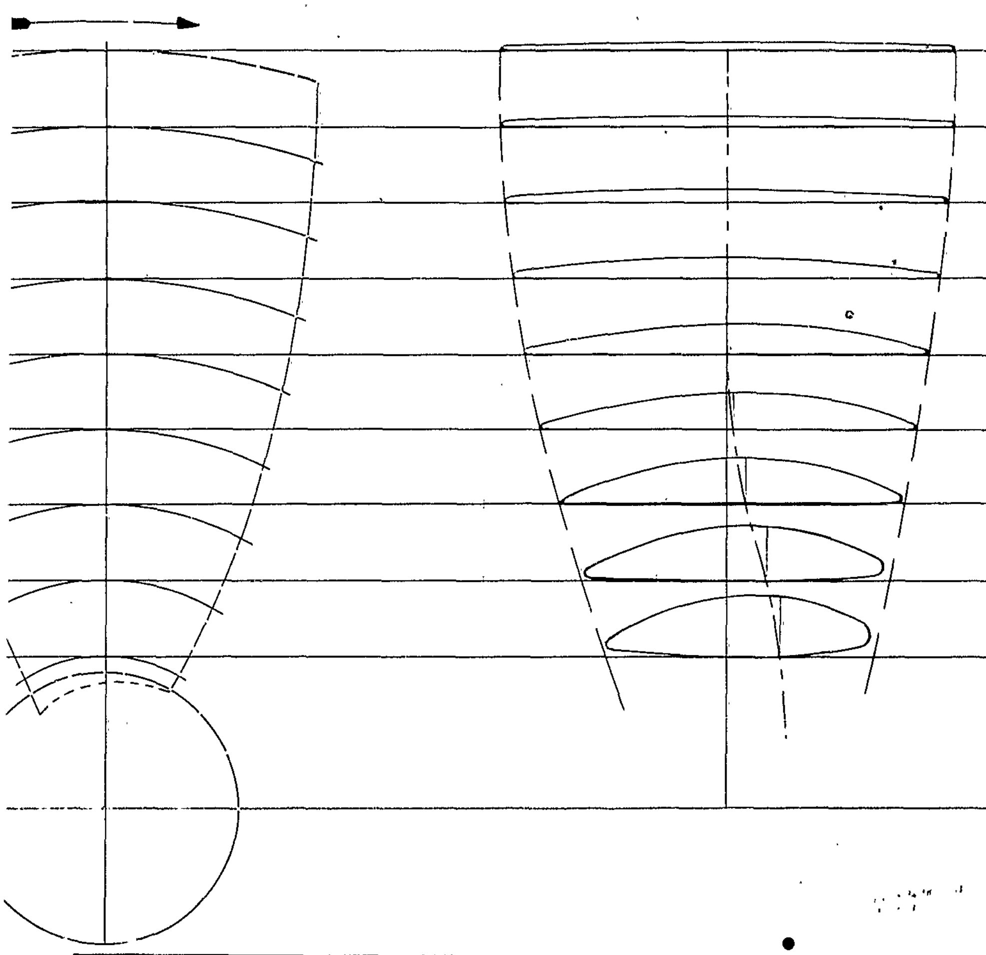

No	RADIUS	MAX. THICKNESS
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0.6	72.0	4.56
0.5	60.0	5.89
0.4	48.0	7.20
0.3	36.0	8.45
0.2	24.0	9.60

PARTICULARS OF PROPELLER MODEL

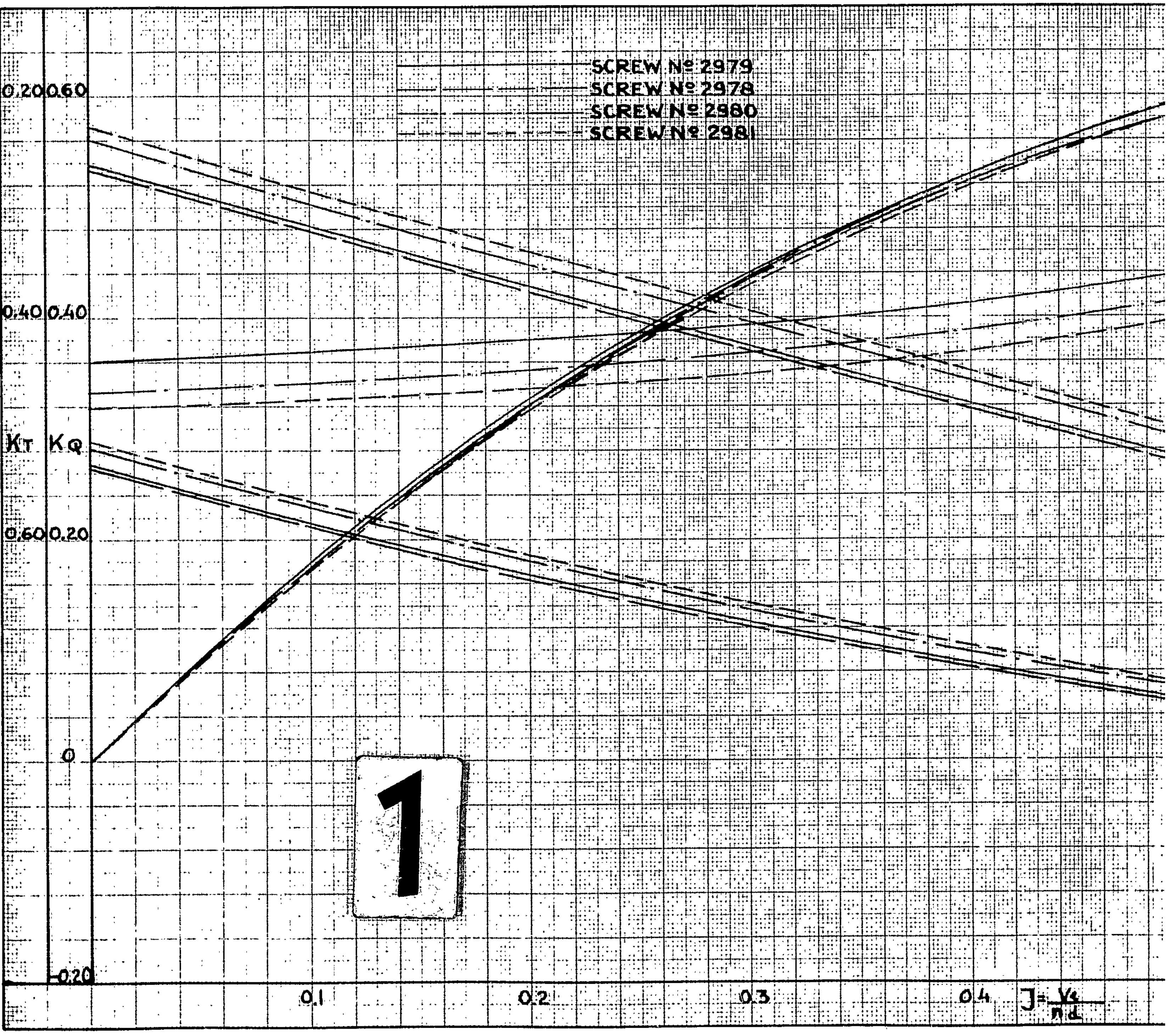
DIAMETER $D = 240.00$ mm	
NUMBER OF BLADES $Z = 4$	HUB DIAMETER RATIO $d_n/d = 0.167$
PITCH AT ROOT $H_n = 200.00$ mm	PITCH RATIO AT 0.7R $H_{0.7}/D = 1.000$
PITCH AT BLADE TIP $H_o = 300.48$ mm	B.A.R. $F_a/F = 0.55$
PITCH AT 0.7 R $H_{0.7R} = 240.00$ mm	MATERIAL BRONZE

PROPELLER MODEL No 2981

DRAWING No S 2981 - 1

2

FIG. 4



SCREW Nº 2979
SCREW Nº 2978
SCREW Nº 2980
SCREW Nº 2981
0.20
0.60
0.40
0.40
KT
KQ
0.60
0.20
0
-0.20
0.1
0.2
0.3
0.4
J = Va/nd
1

OPEN WATER TEST REPORT

$\sigma_n = 34.5$

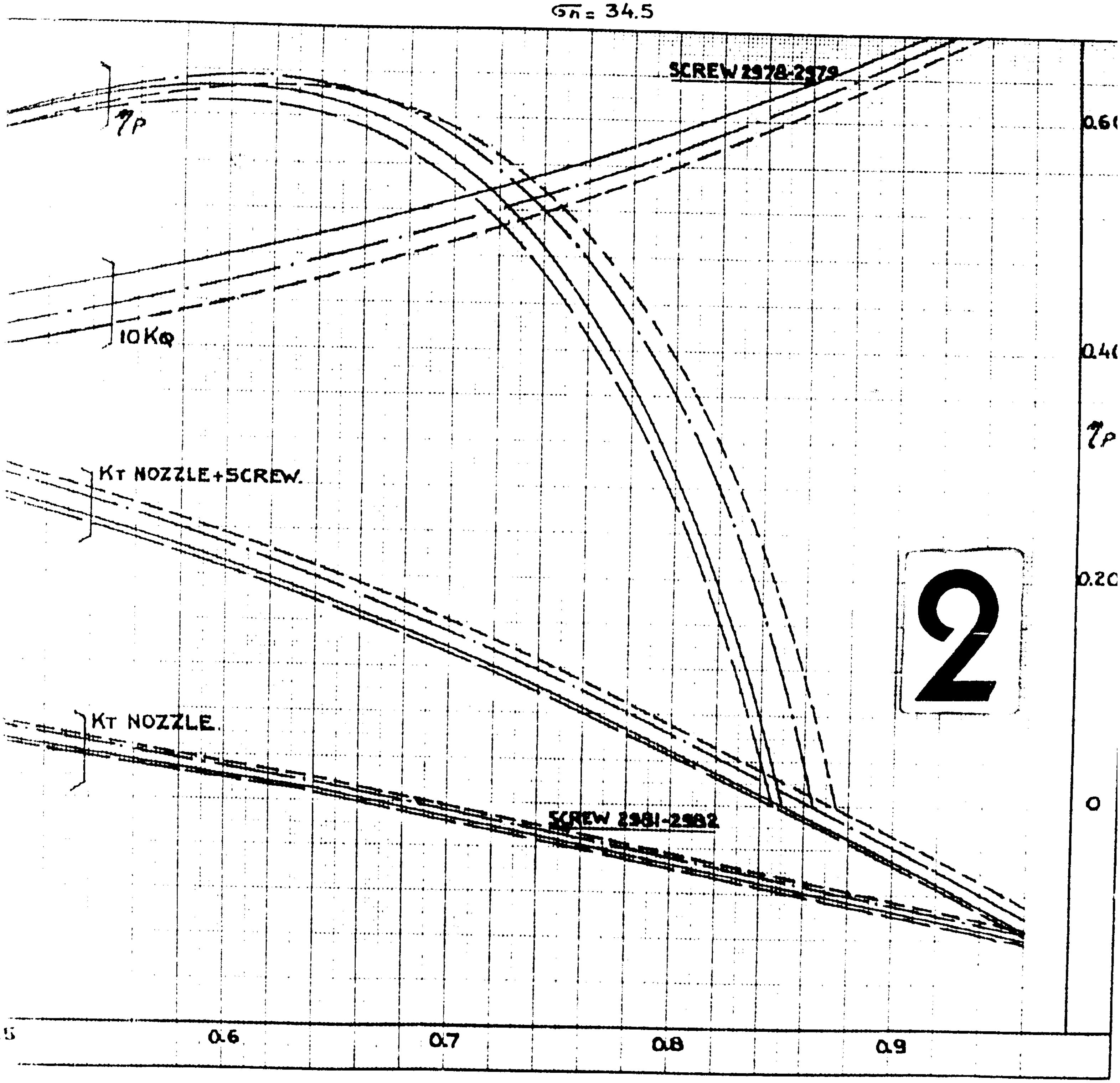


FIG.5

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 22

RELATION BETWEEN BLADE TIP CLEARANCE AND EFFICIENCY LOSS AT $\sigma_m = 3.45$ (TOWING TANK).

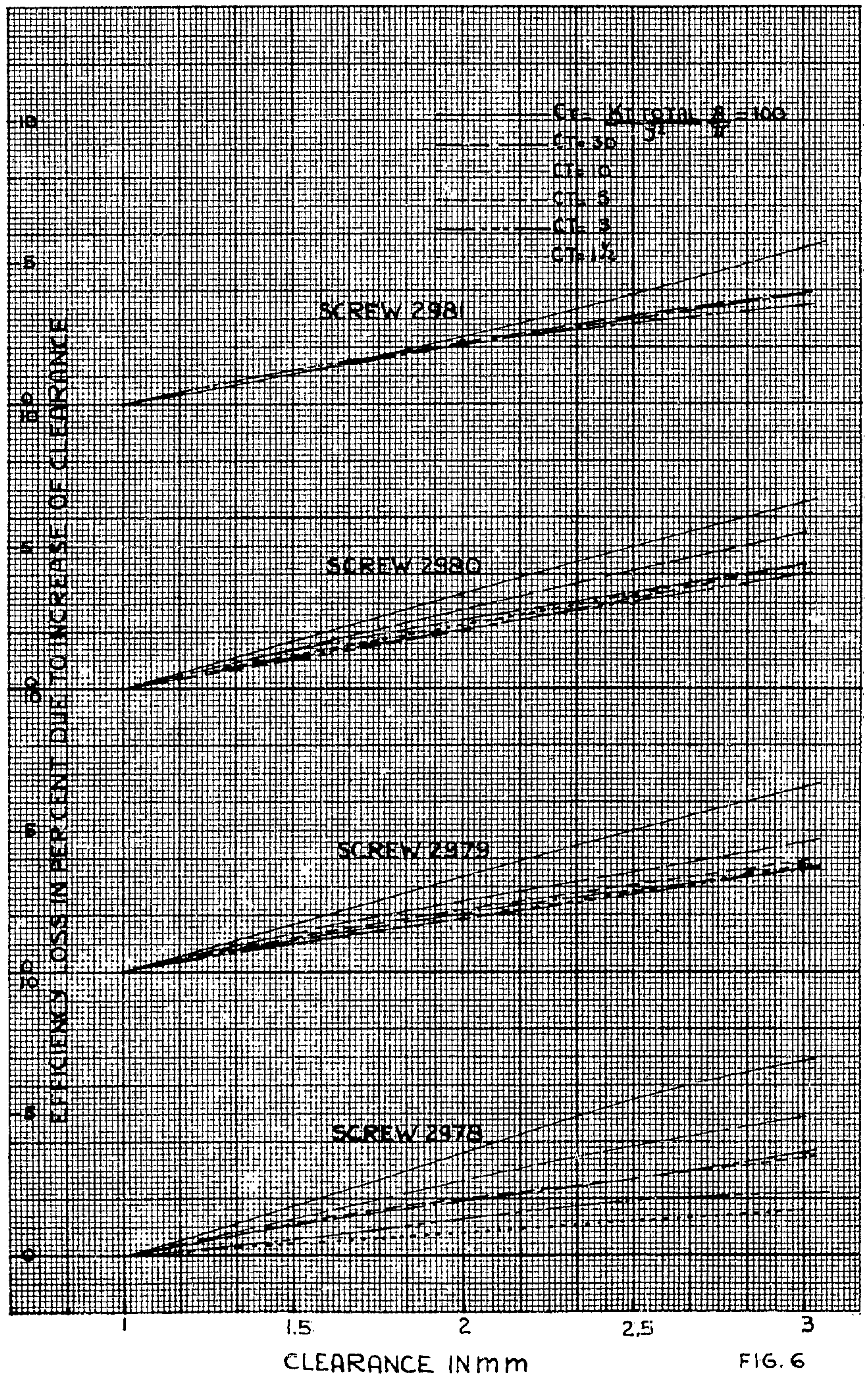
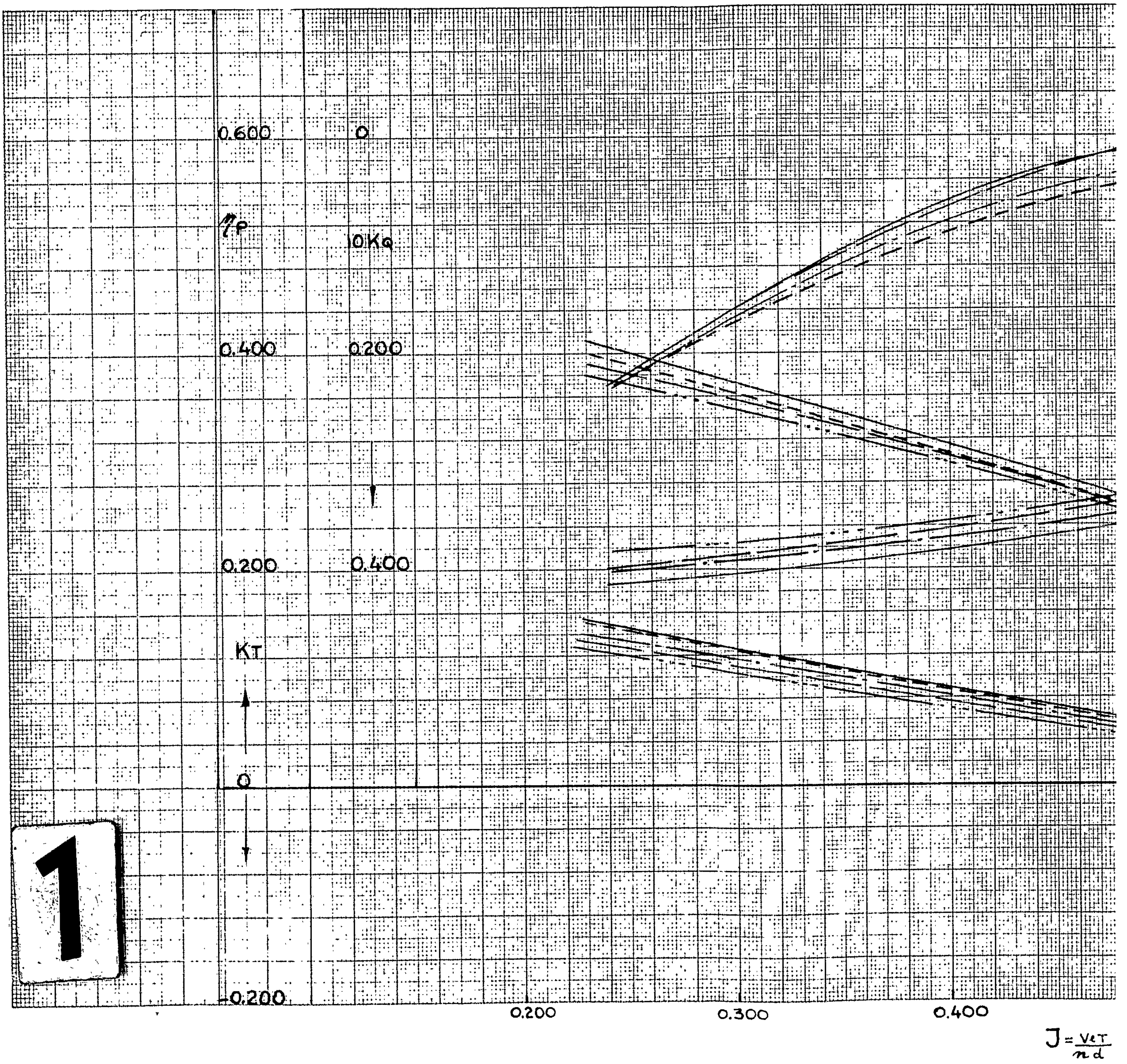


FIG. 6

PROPELLER MODEL 2

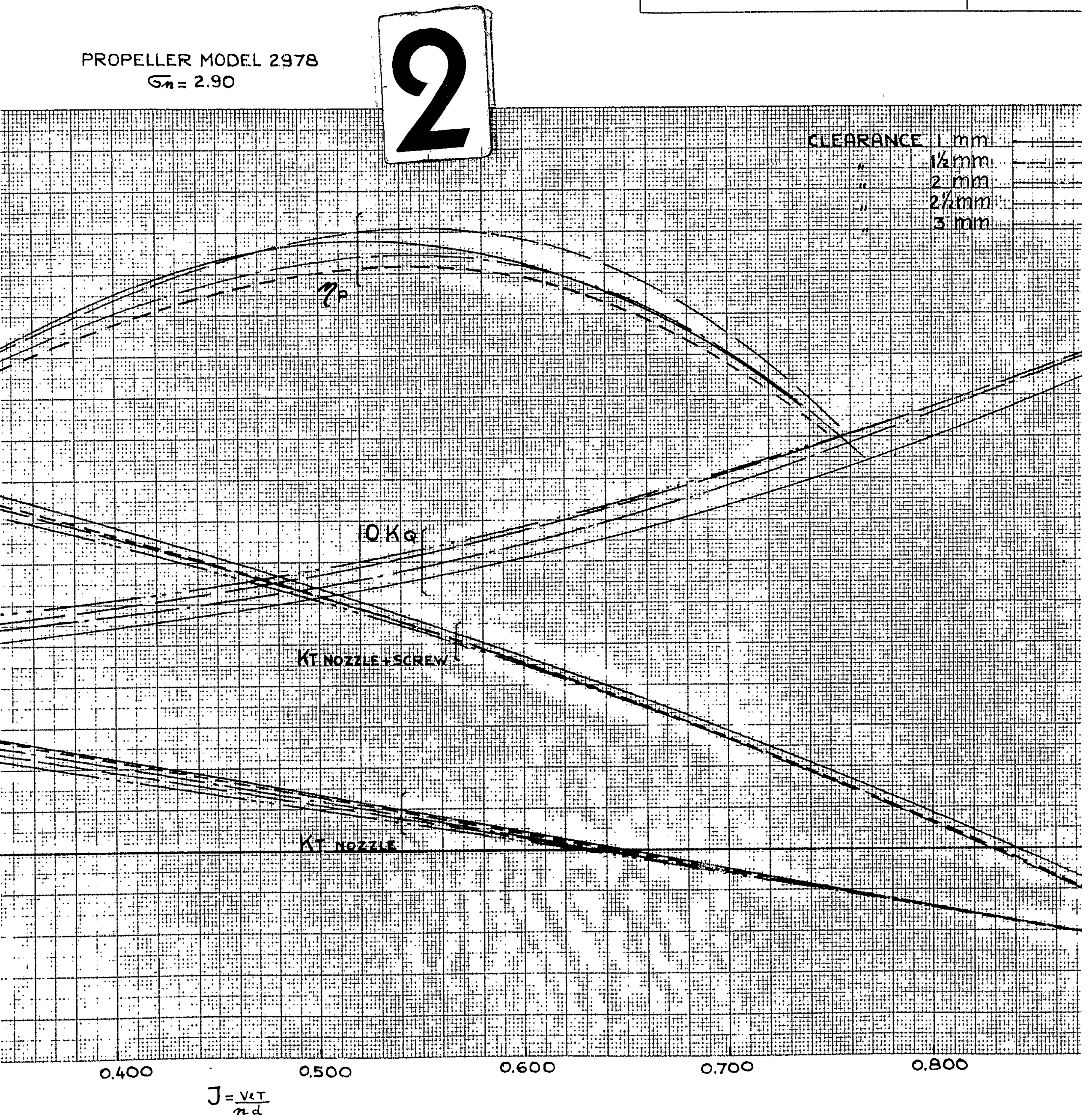
$\sigma_n = 2.90$



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN

CAVITATION T
NO.

PROPELLER MODEL 2978
$\sigma_n = 2.90$



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 23

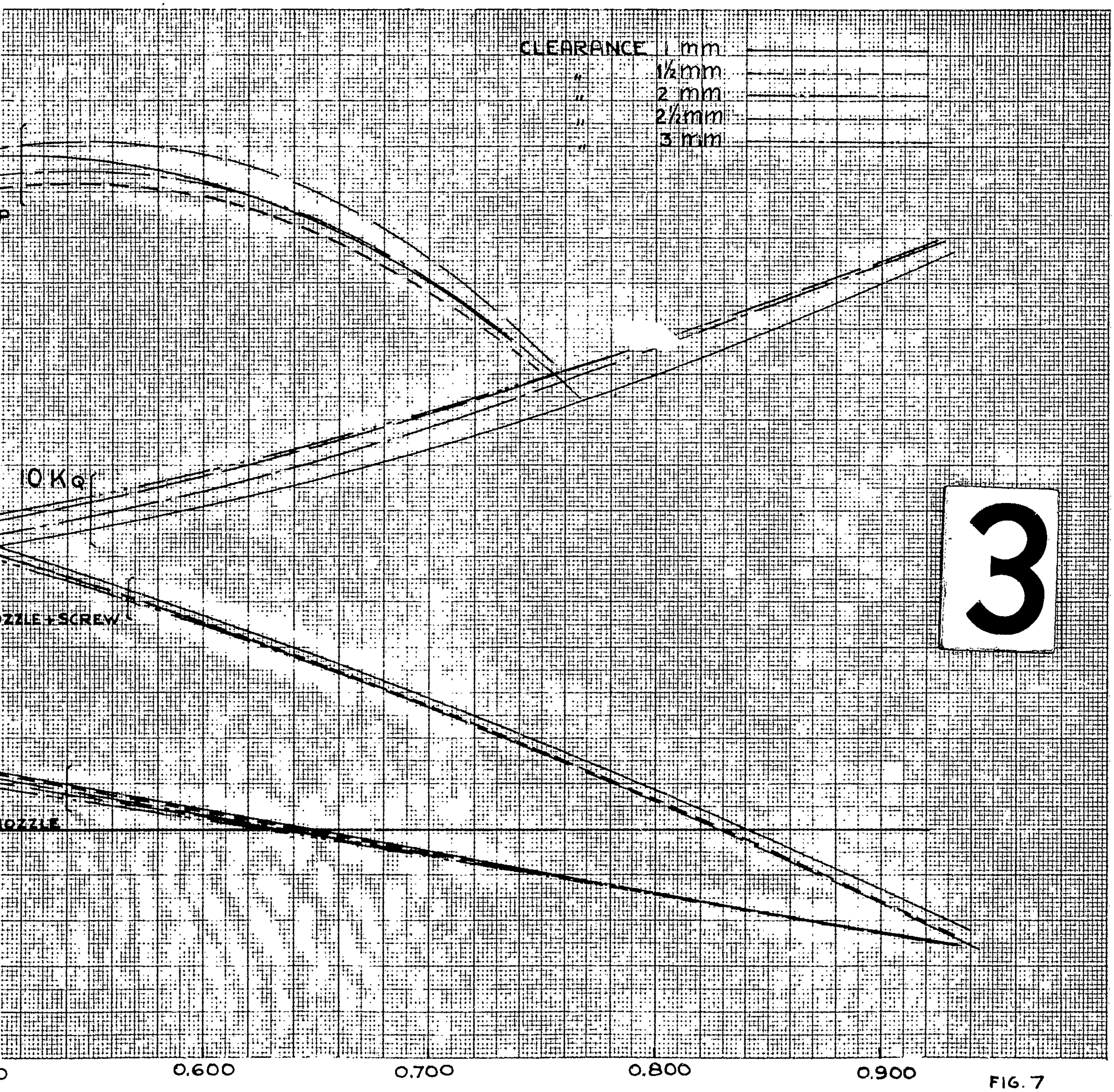
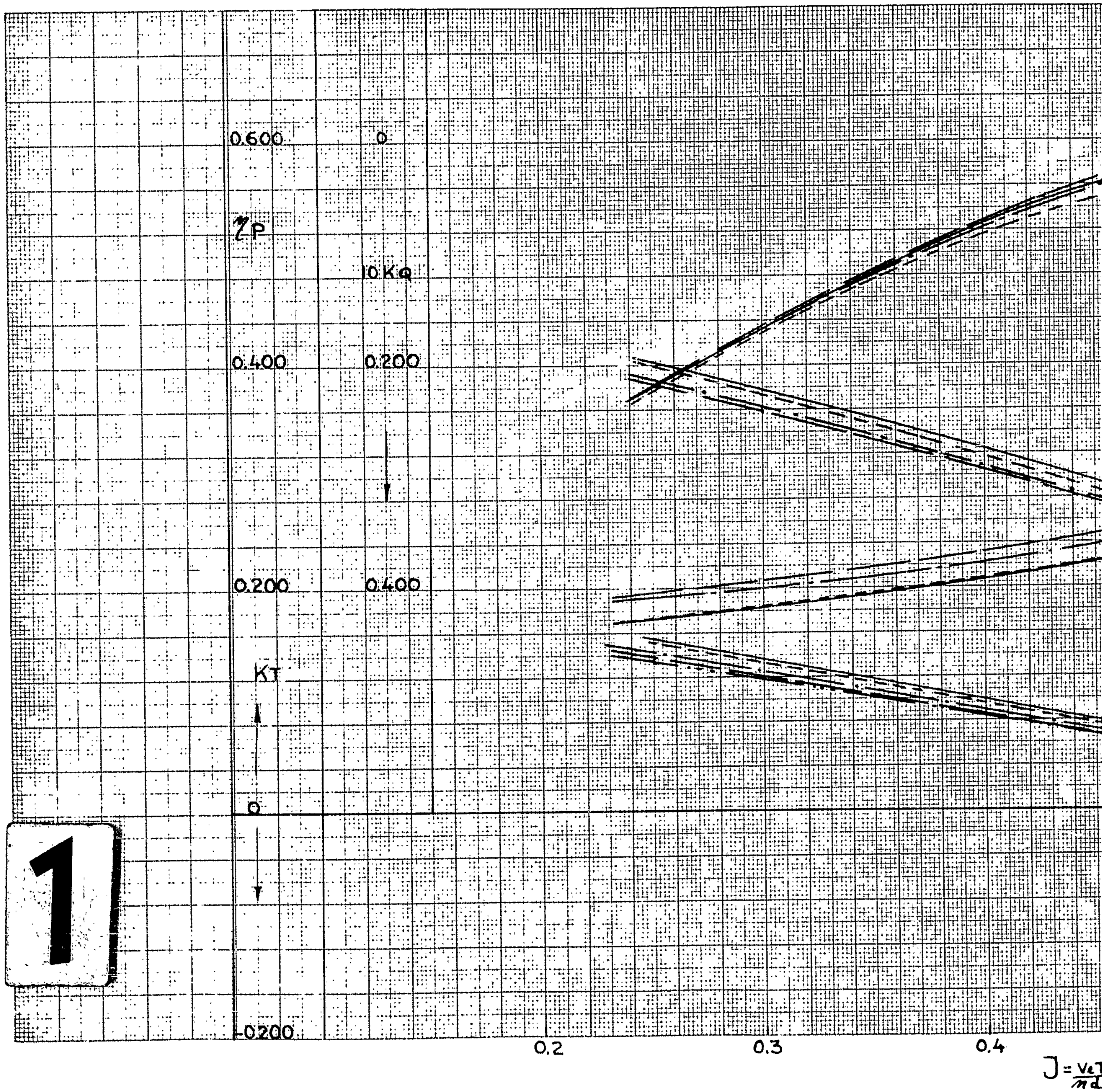


FIG. 7

PROPE
C

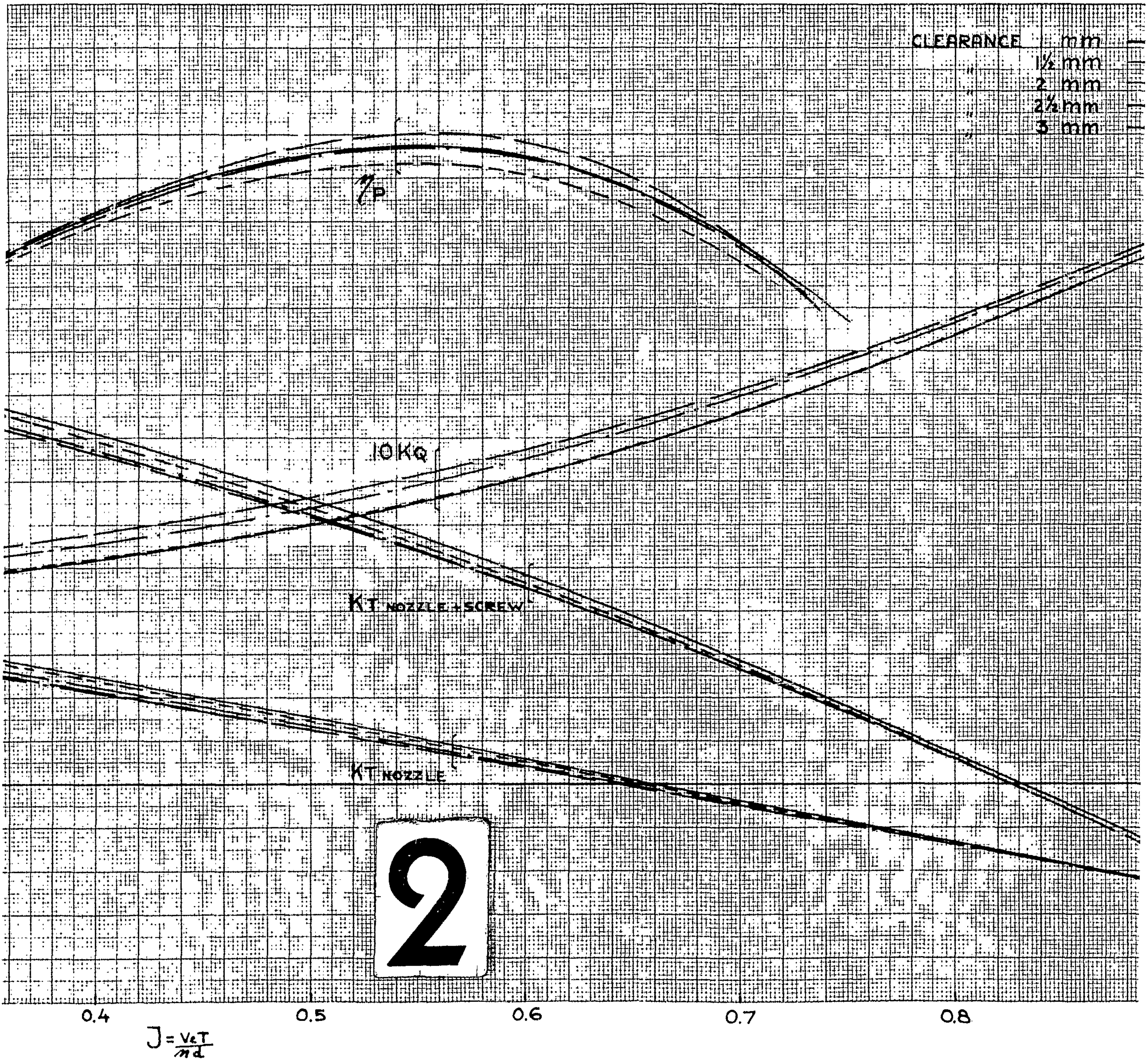


0.600
0
η_P
10 KQ
0.400
0.200
0.200
0.400
KT
0
-0.200
0.2
0.3
0.4
J = $\frac{V_e}{nd}$
1

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN

CAVITATION TES
NO. 535

PROPELLER MODEL 2979
$\sigma_n = 2.90$



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 24

. 2979

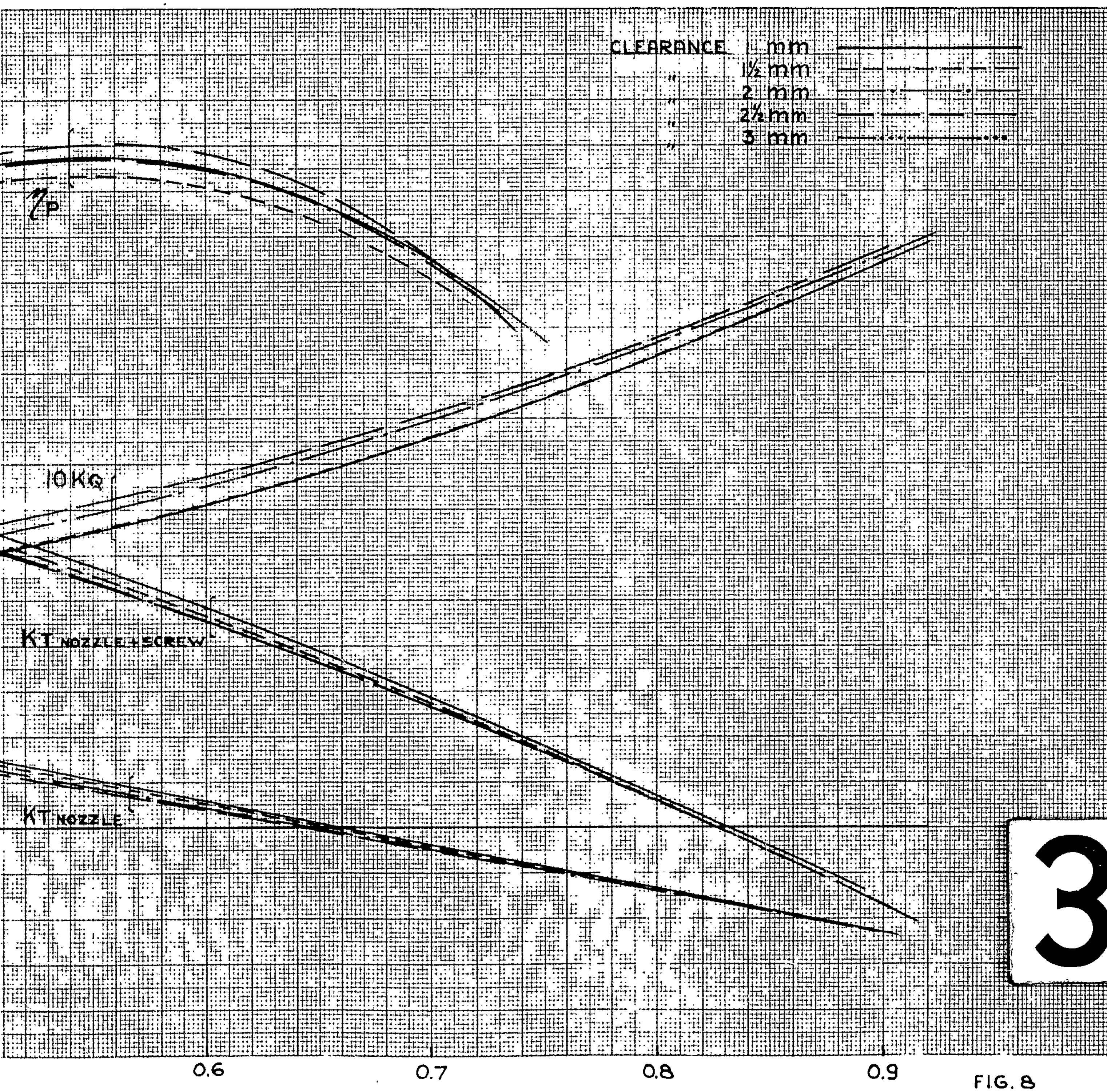
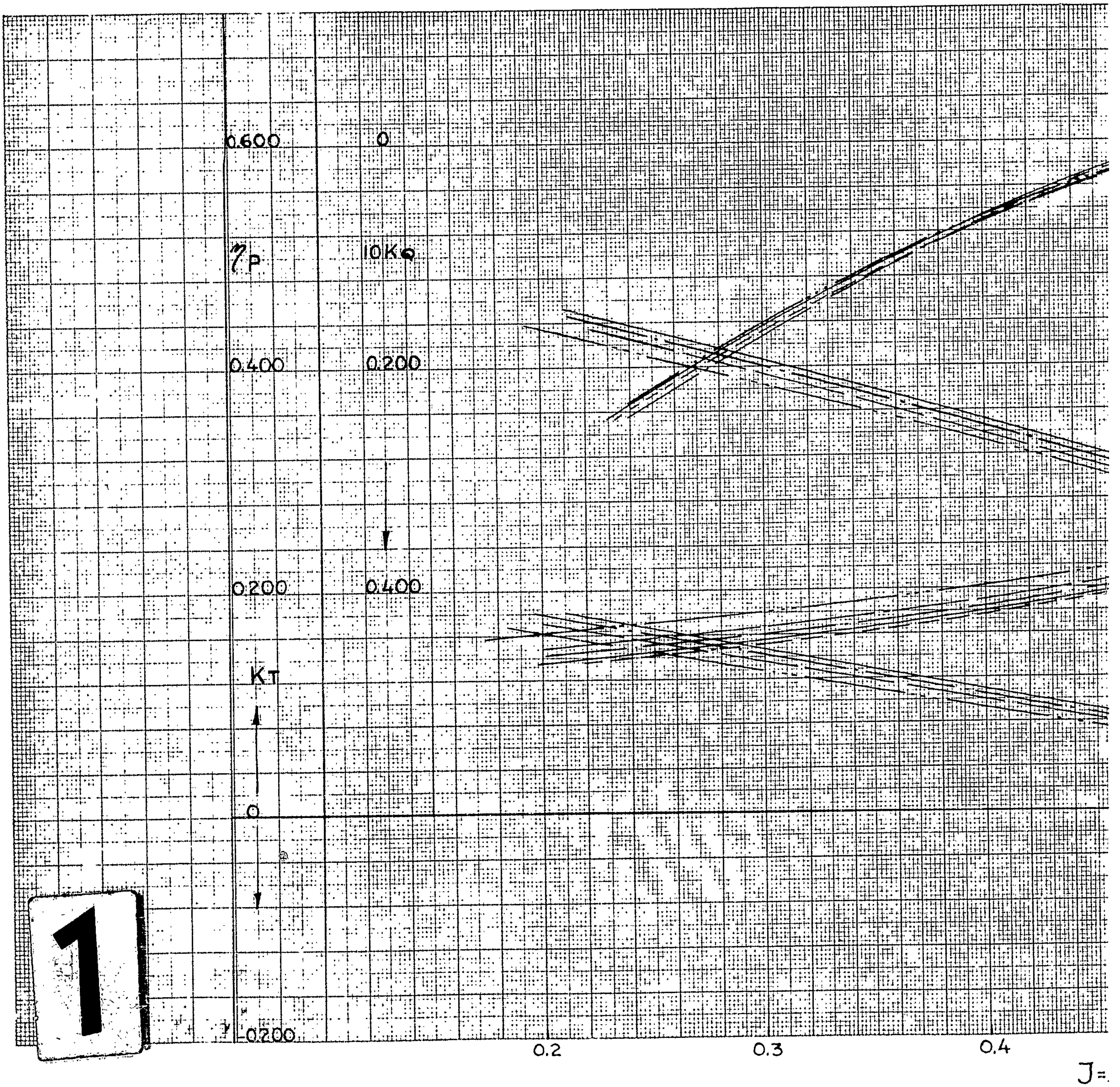


FIG. 8

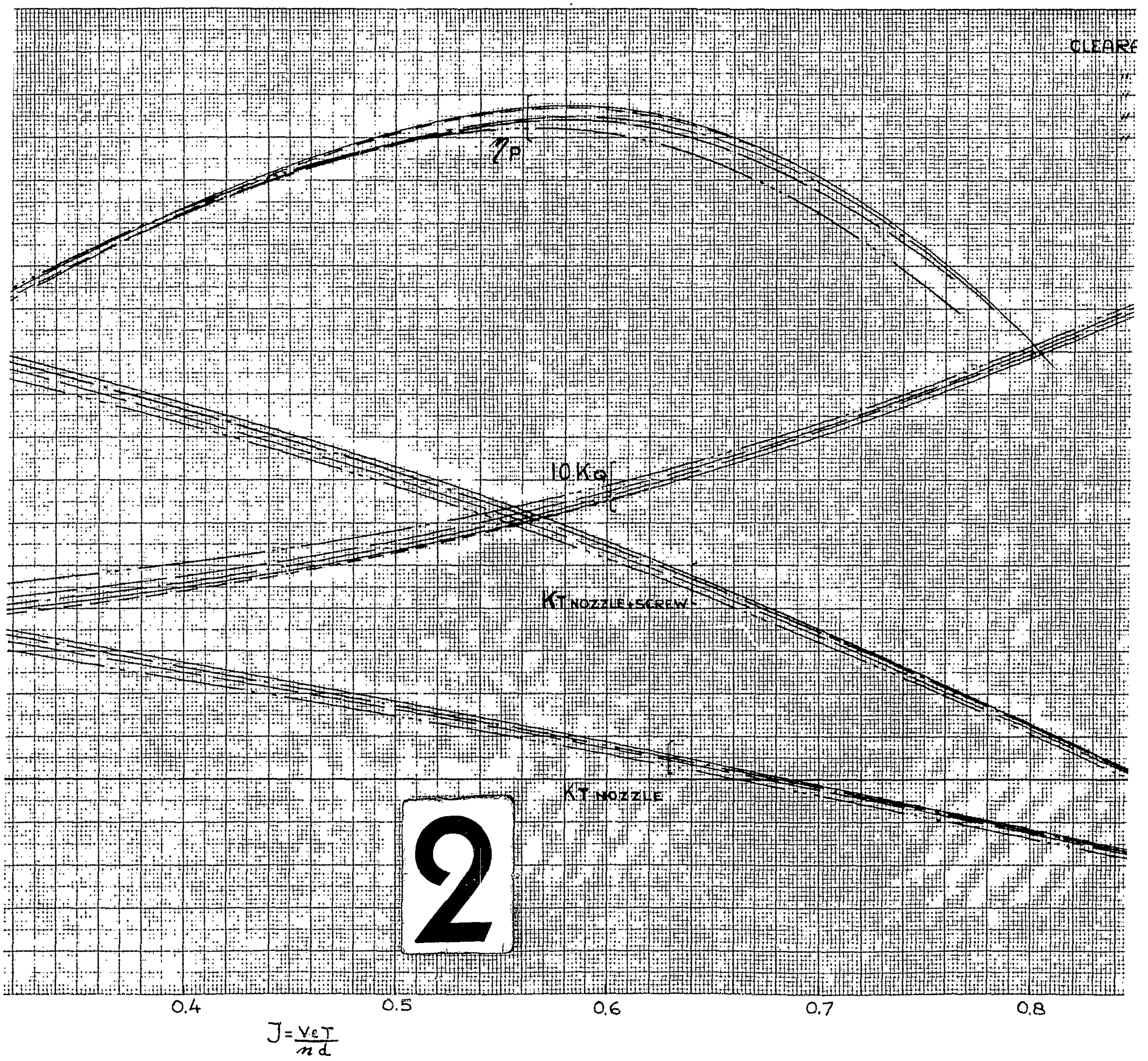
3



0.600
0
η_P
10KQ
0.400
0.200
0.200
0.400
KT
0
-0.200
0.2
0.3
0.4
J=
1

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITA

PROPELLER MODEL 2980
$\sigma_n = 2.90$



LER MODEL 2980

σ_n = 2.90

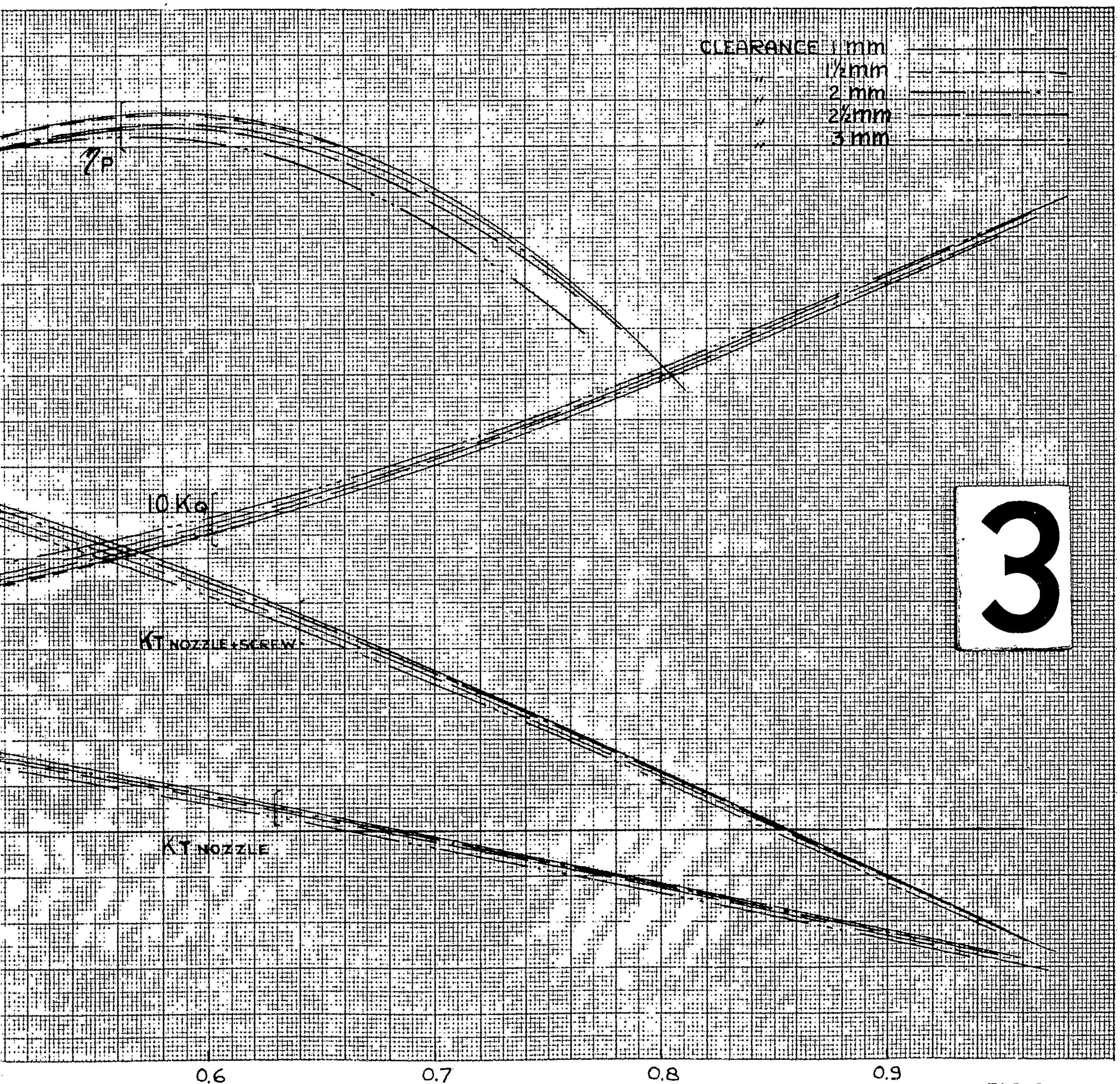
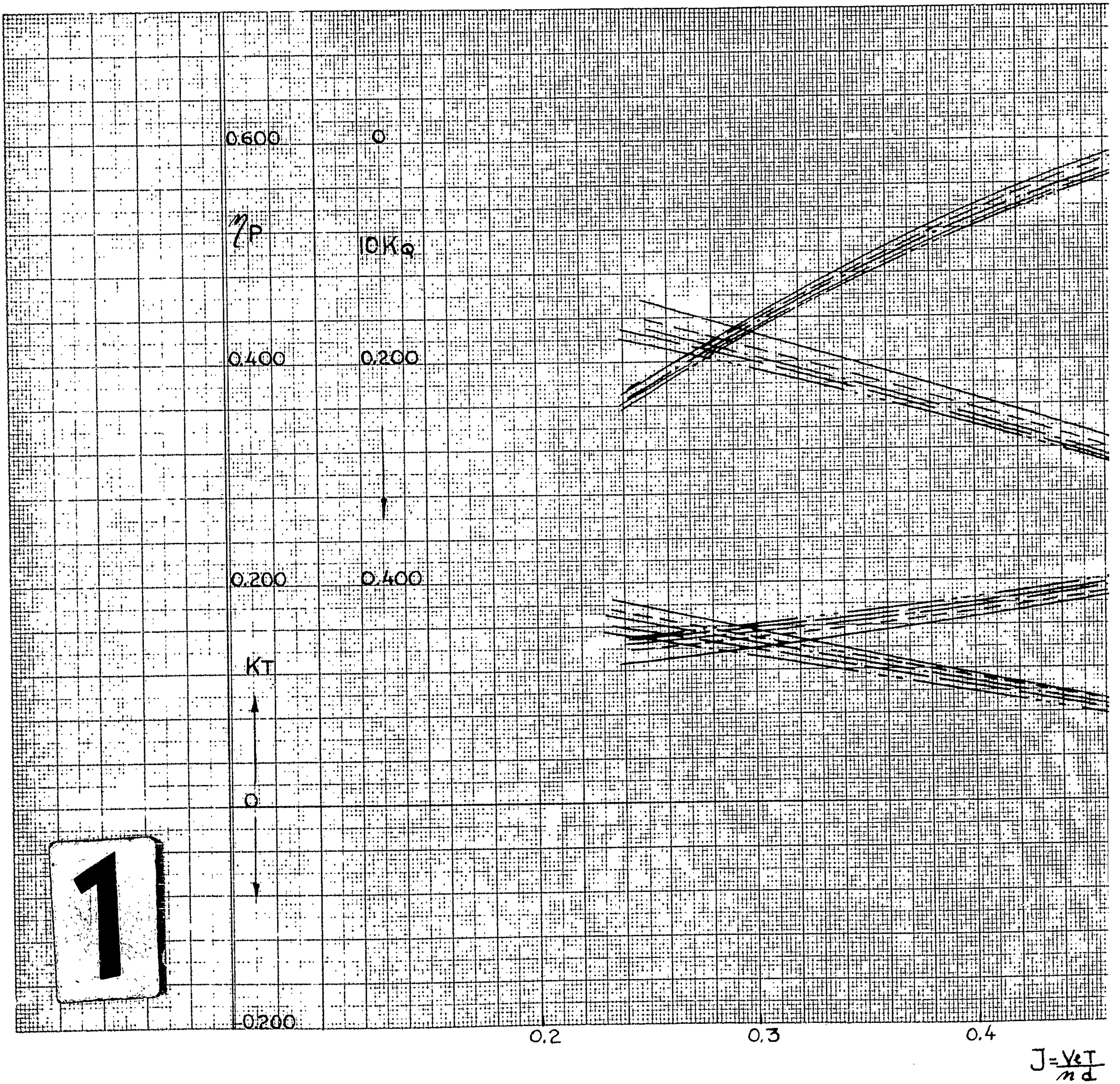


FIG. 9

PROP

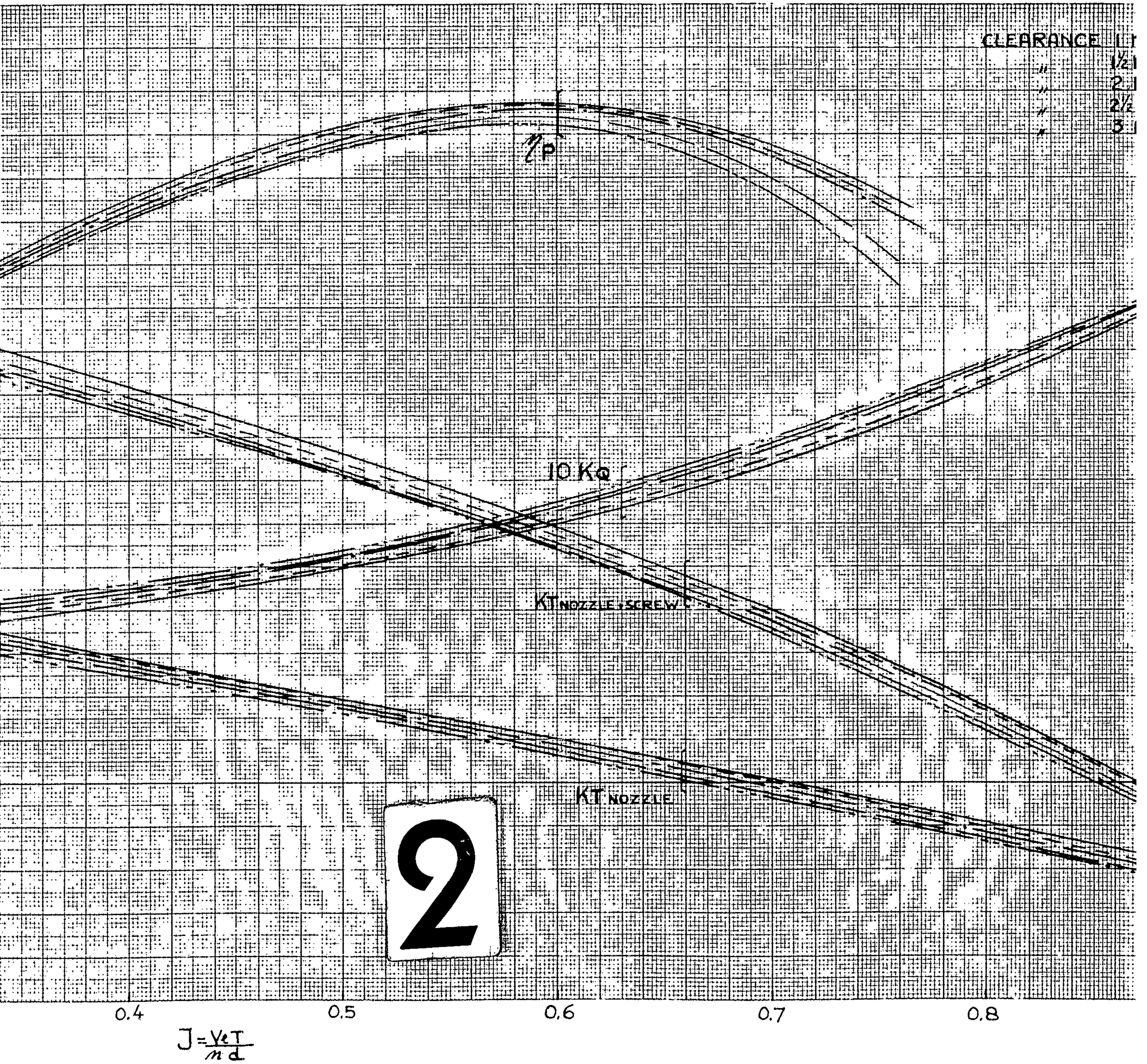


0.600
0
η_P
$10K_Q$
0.400
0.200
0.200
0.400
K_T
0
-0.200
0.2
0.3
0.4
$J = \frac{V_e T}{n d}$
1

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATIO NO

PROPELLER MODEL 2981

$\sigma_n = 2.90$



)DEL 2981
)

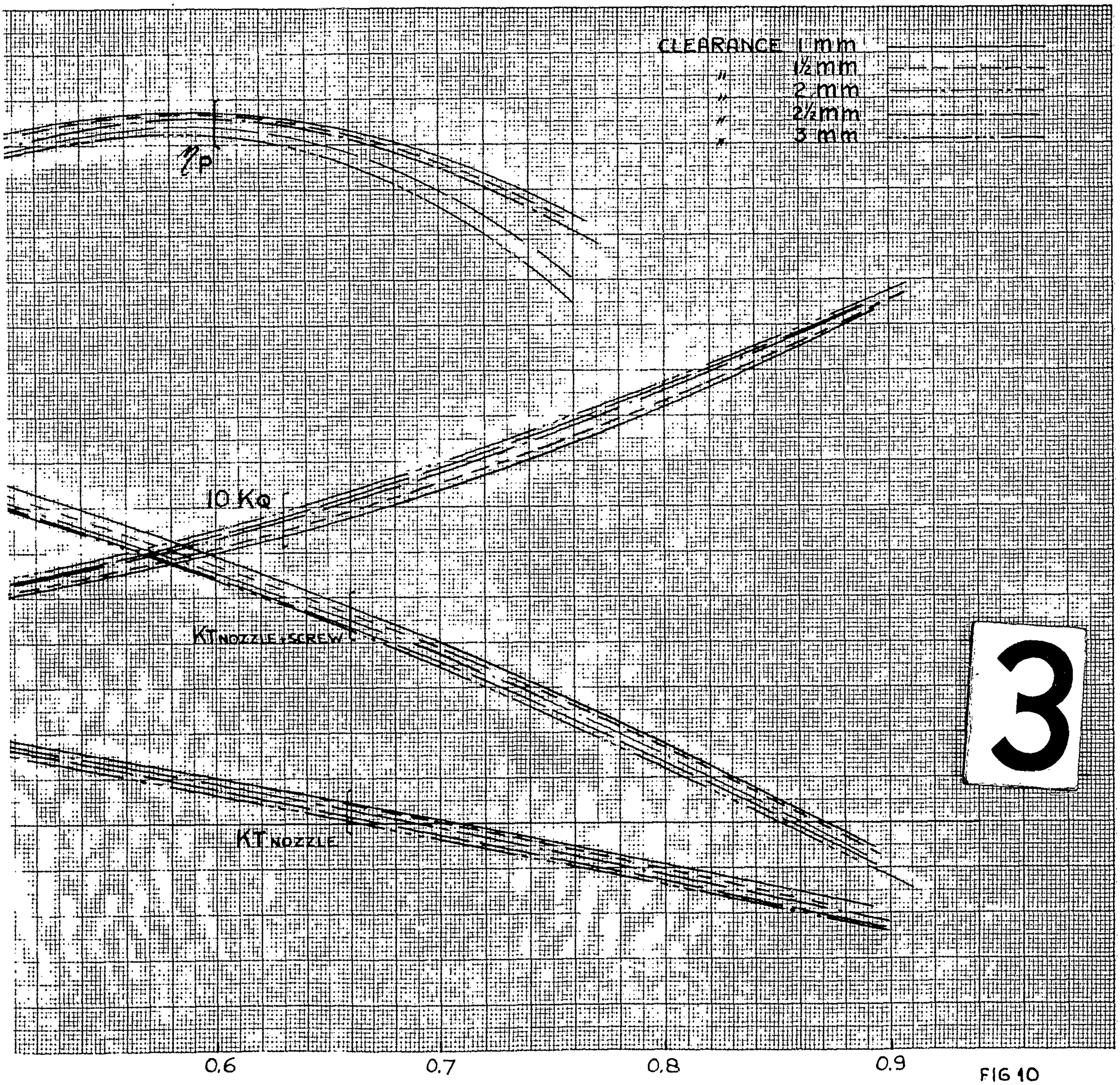
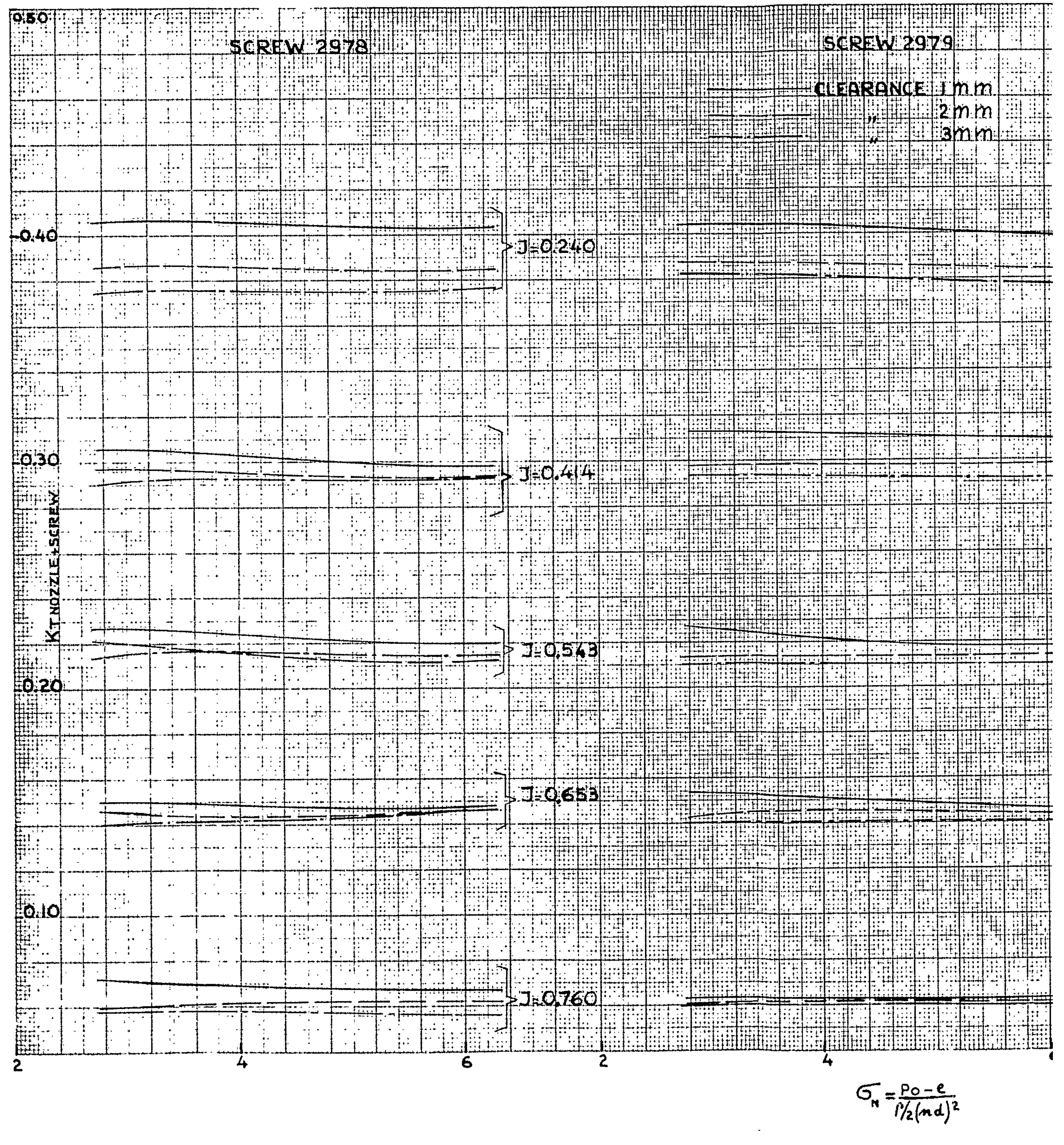


FIG 10

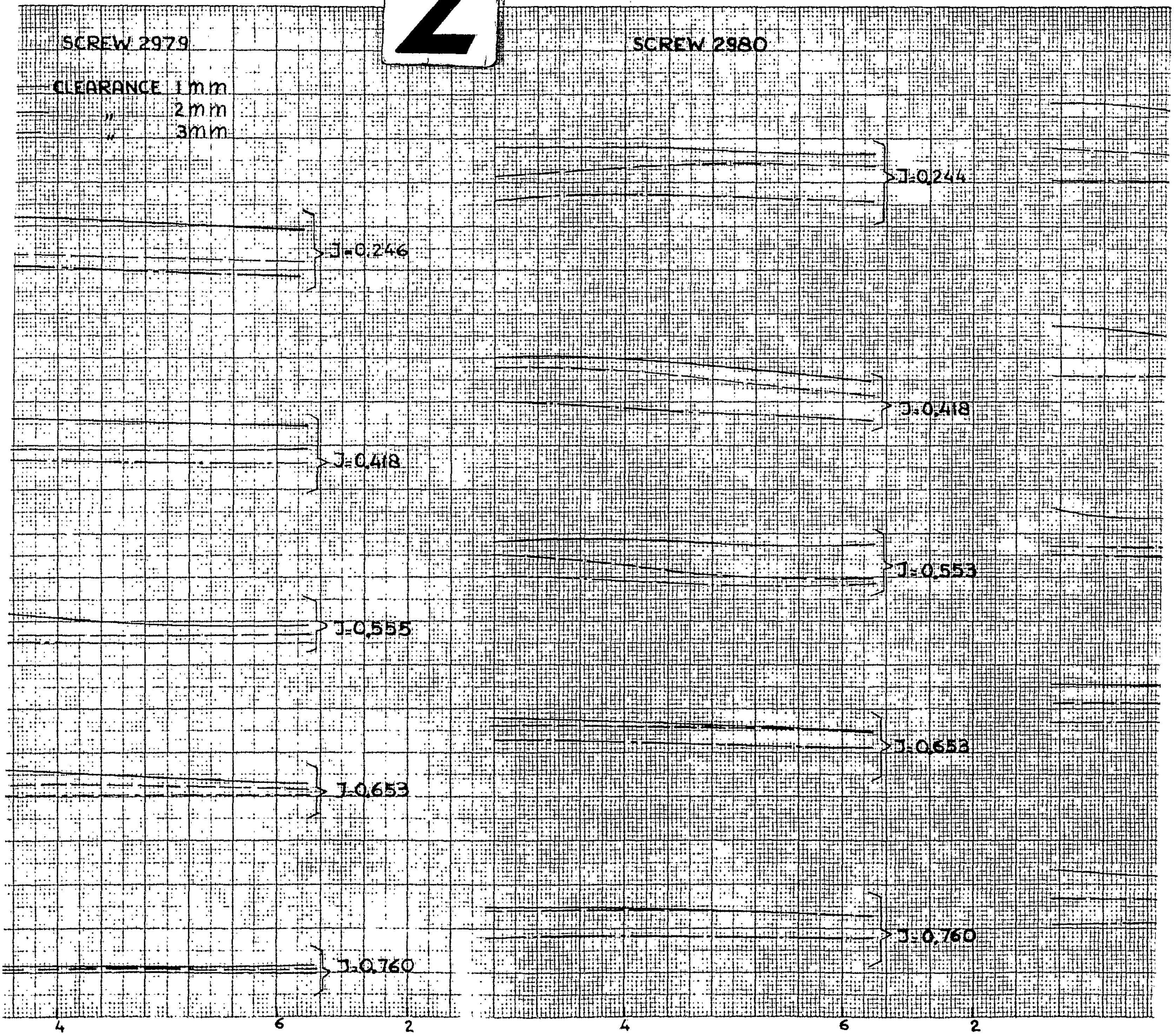

SCREW 2978
SCREW 2979
CLEARANCE 1mm
" 2mm
" 3mm
0.50
0.40
0.30
0.20
0.10
$K_{T\ NOZZLE+SCREW}$
J=0.240
J=0.414
J=0.543
J=0.653
J=0.760
2
4
6
2
4
$\sigma_N = \frac{Po - e}{1/2\rho(nd)^2}$

1

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN | CA

INFLUENCE OF CAVITATION NUMBER
ON PROPELLER PE

2



$\sigma_N = \frac{Po - e}{\rho/2 (nd)^2}$

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 27

INFLUENCE OF CAVITATION NUMBER AND BLADETIP CLEARANCE ON PROPELLER PERFORMANCE

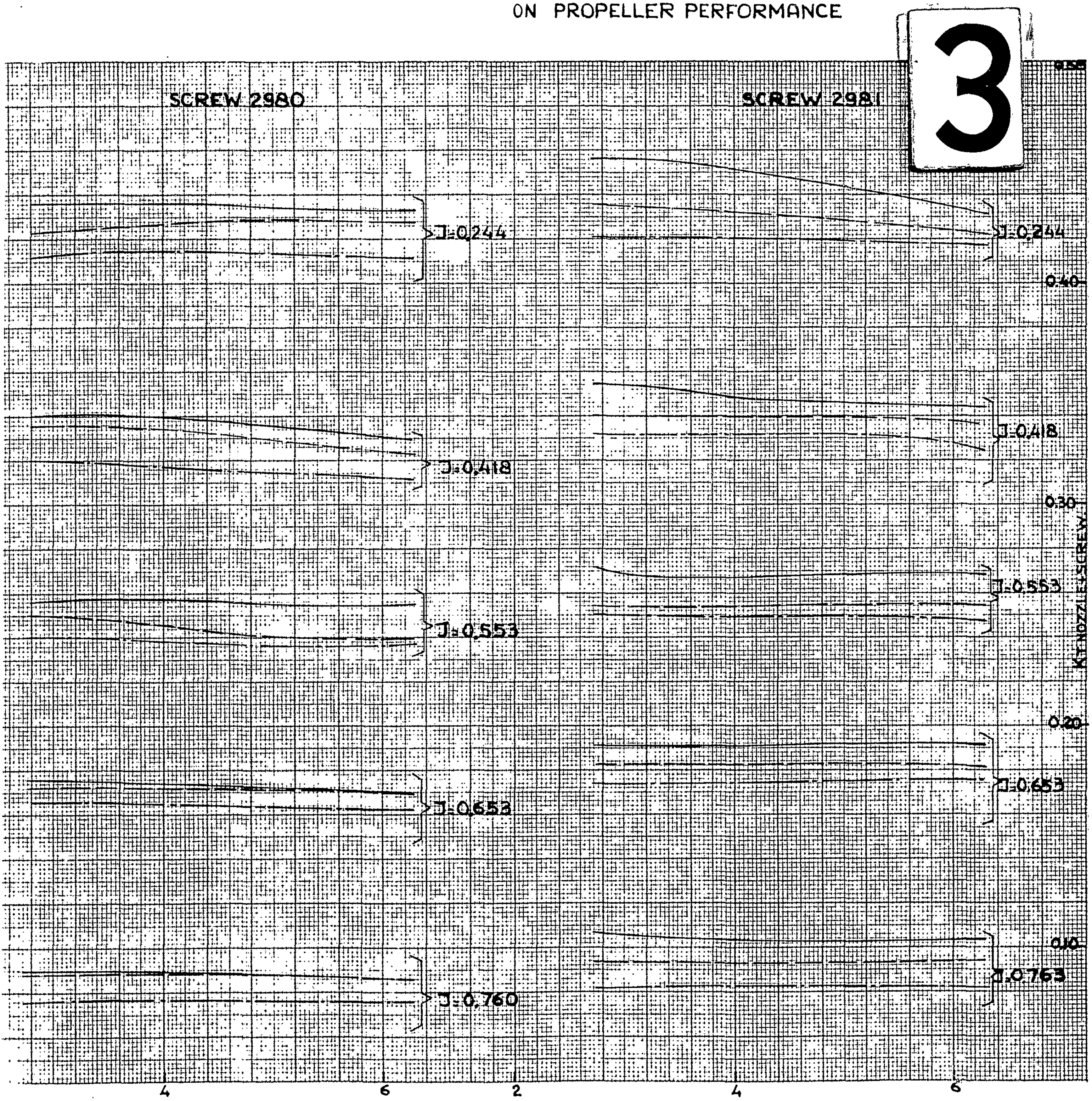
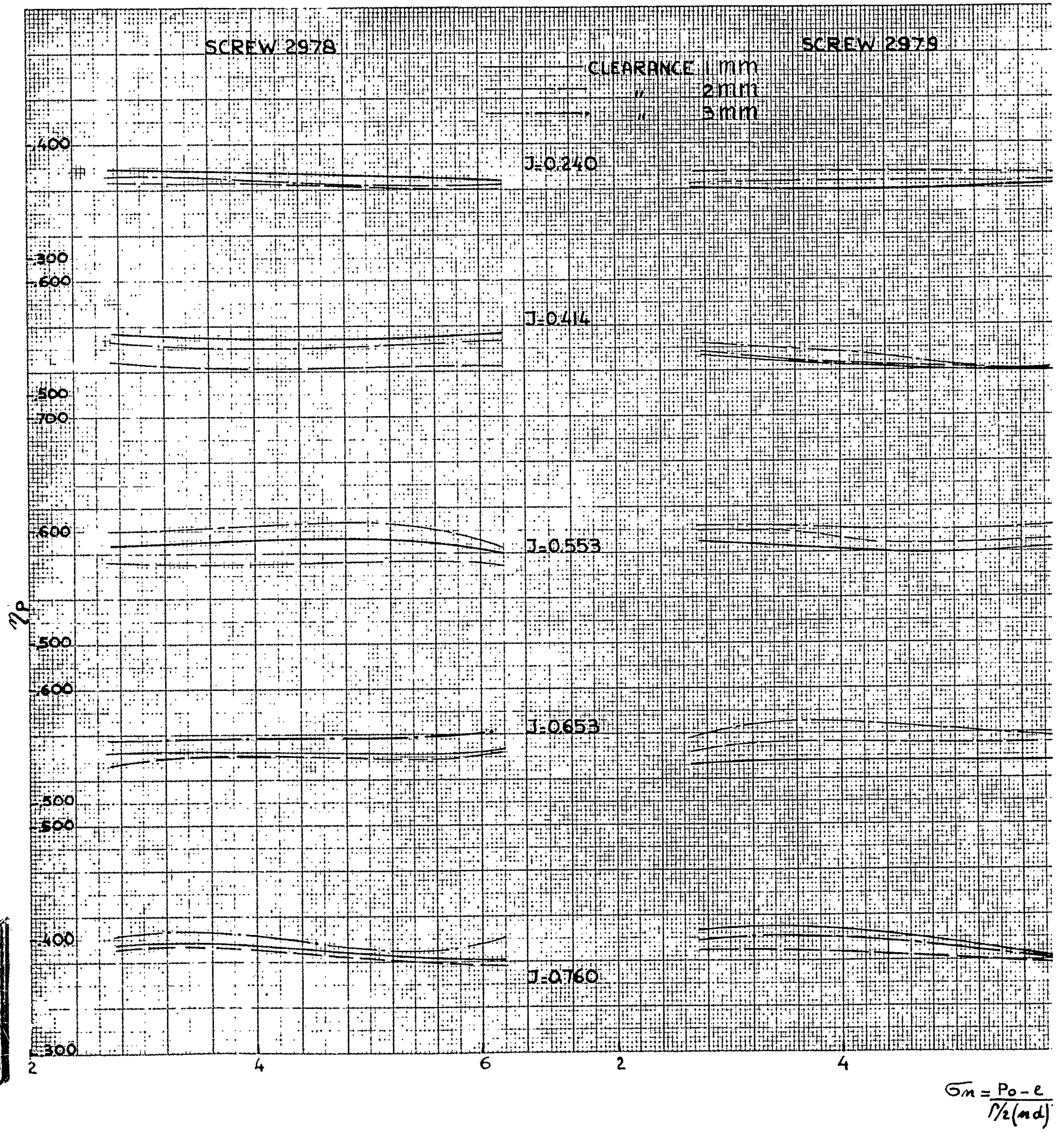


FIG 11

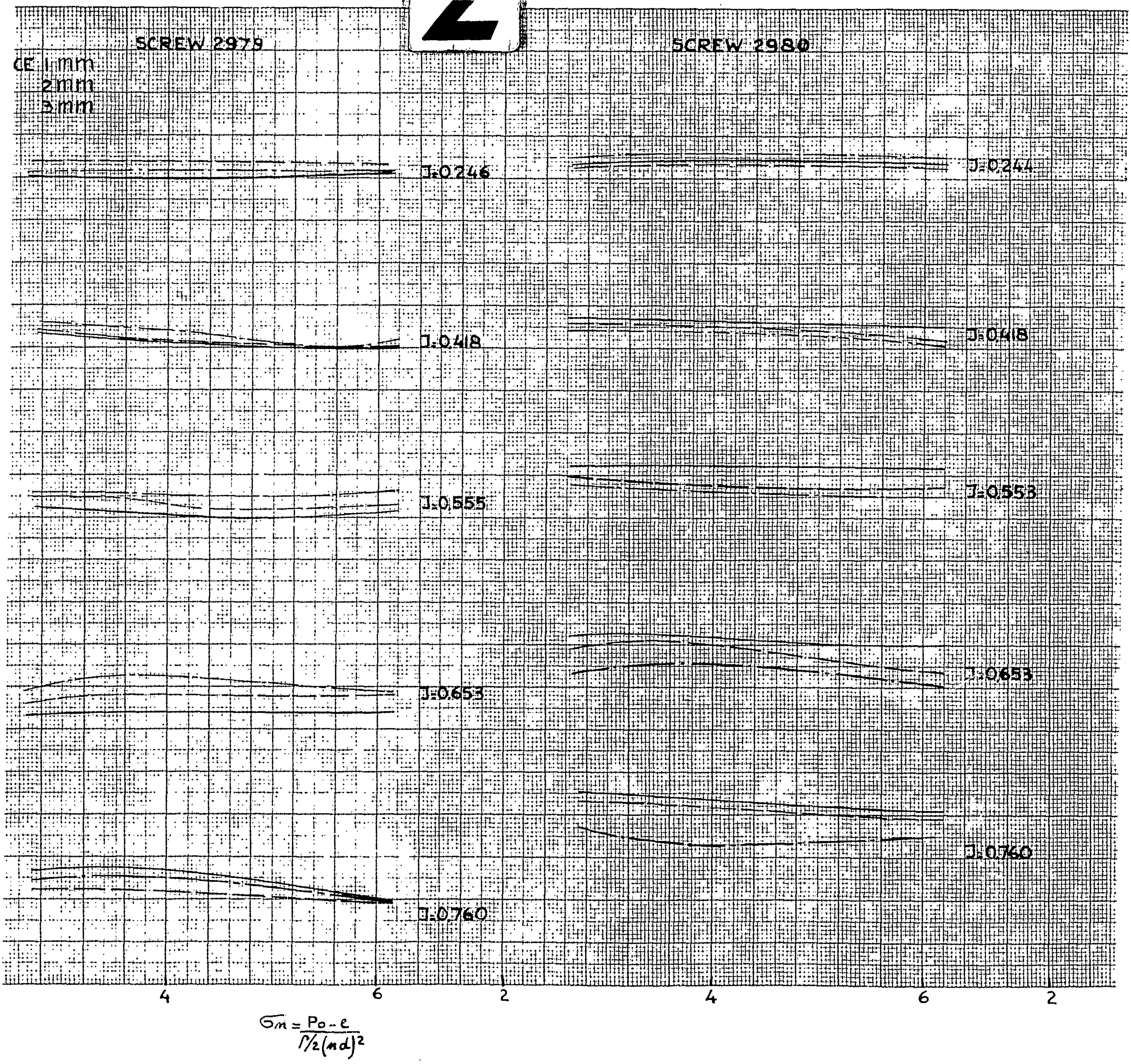


SCREW 2978
SCREW 2979
CLEARANCE 1 mm
" 2 mm
" 3 mm
J=0.240
J=0.414
J=0.553
J=0.653
J=0.760
η_P
.400
.300
.600
.500
.700
.600
.500
.600
.500
.500
.400
.300
2
4
6
2
4
$\sigma_n = \frac{P_o - e}{\rho/2 (nd)^2}$

NEDERLANDSCH SCHEEPSBOUWK
PROEFSTATION WAGEN

INFLUENCE OF CAVIT
ON PR

2



INFLUENCE OF CAVITATION NUMBER AND BLADE TIP CLEARANCE ON PROPELLER PERFORMANCE

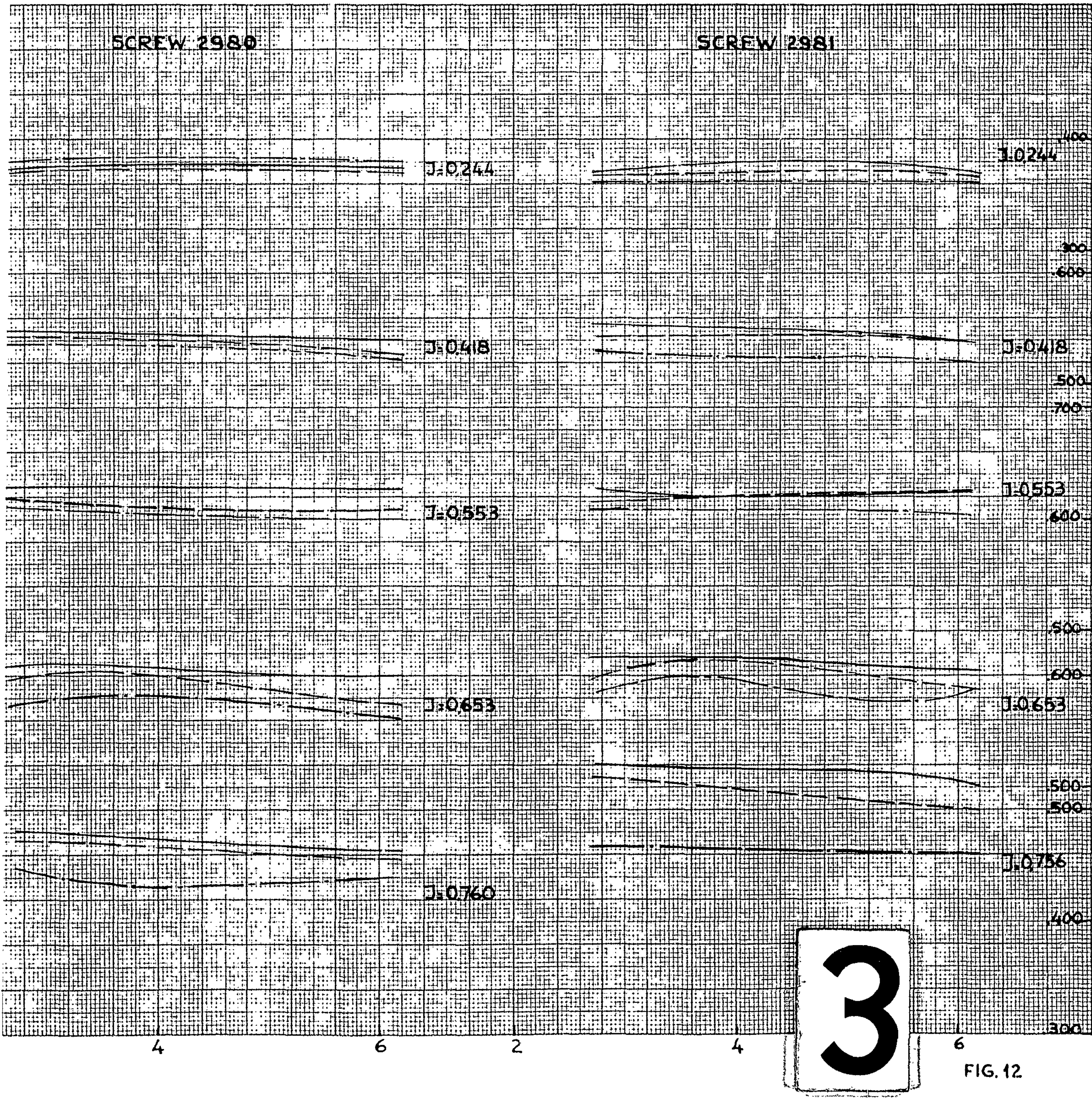


FIG. 12

RELATION BETWEEN BLADE TIP CLEARANCE
AND EFFICIENCY LOSS AT $\sigma_m = 2{,}90$

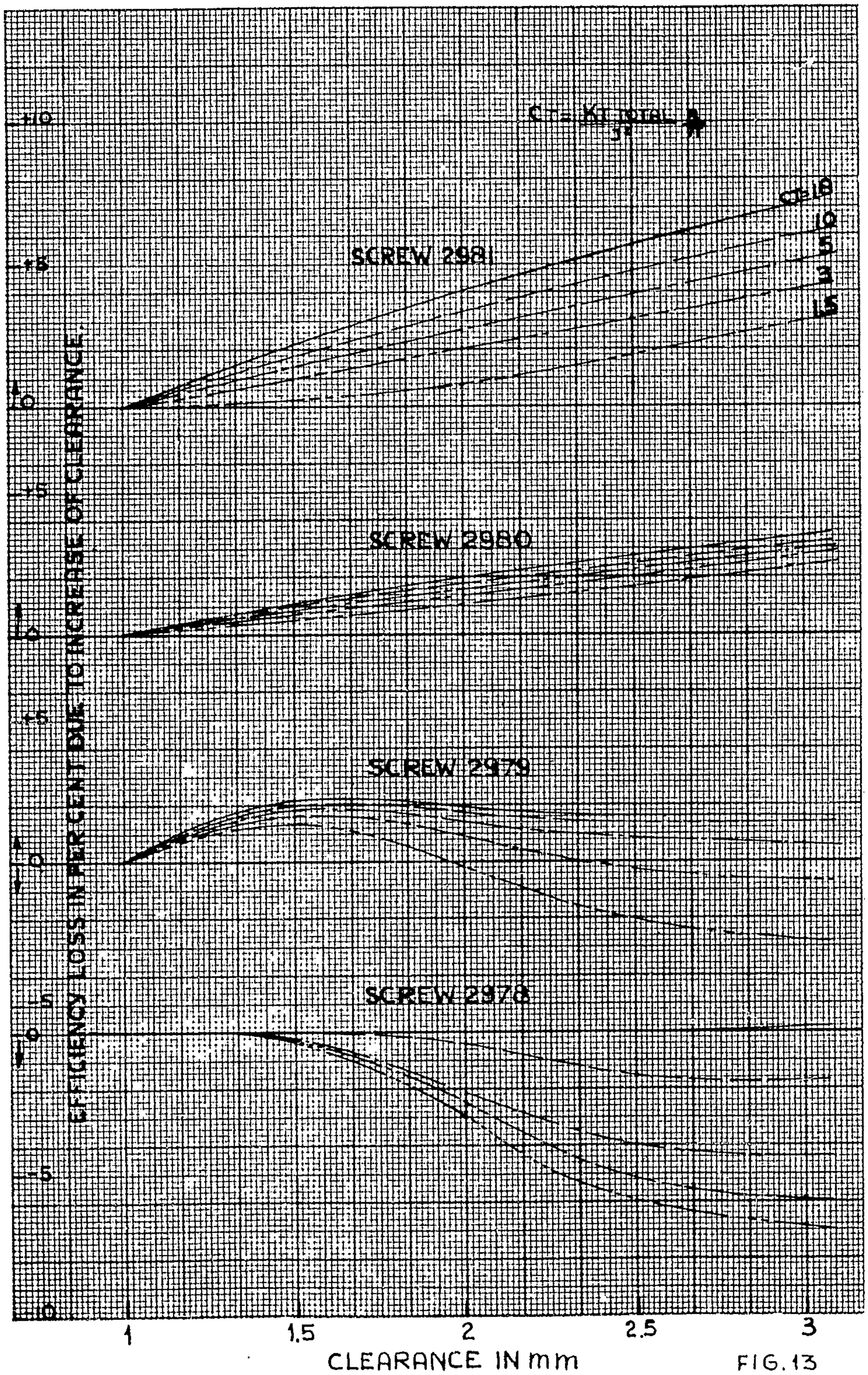
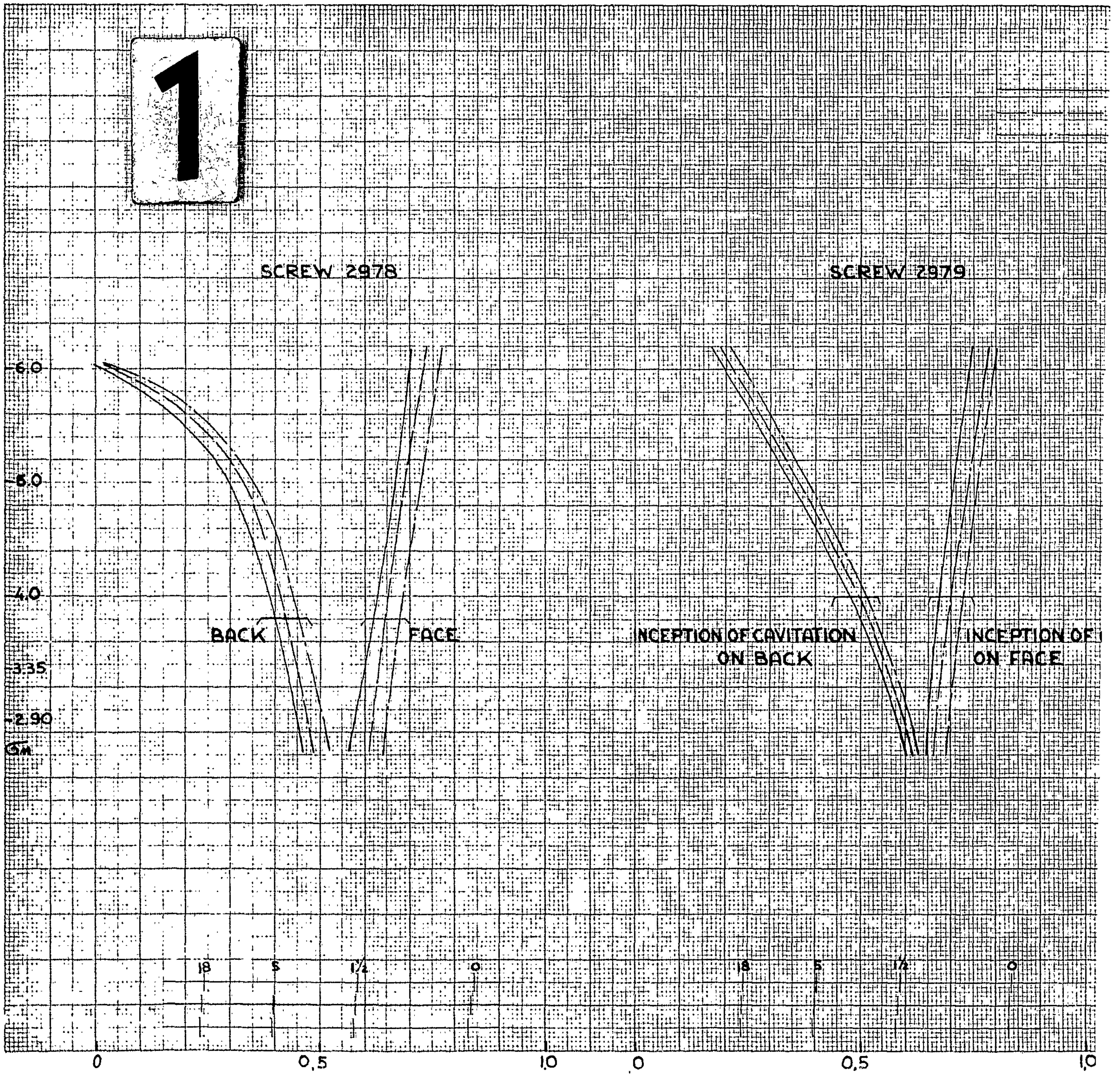


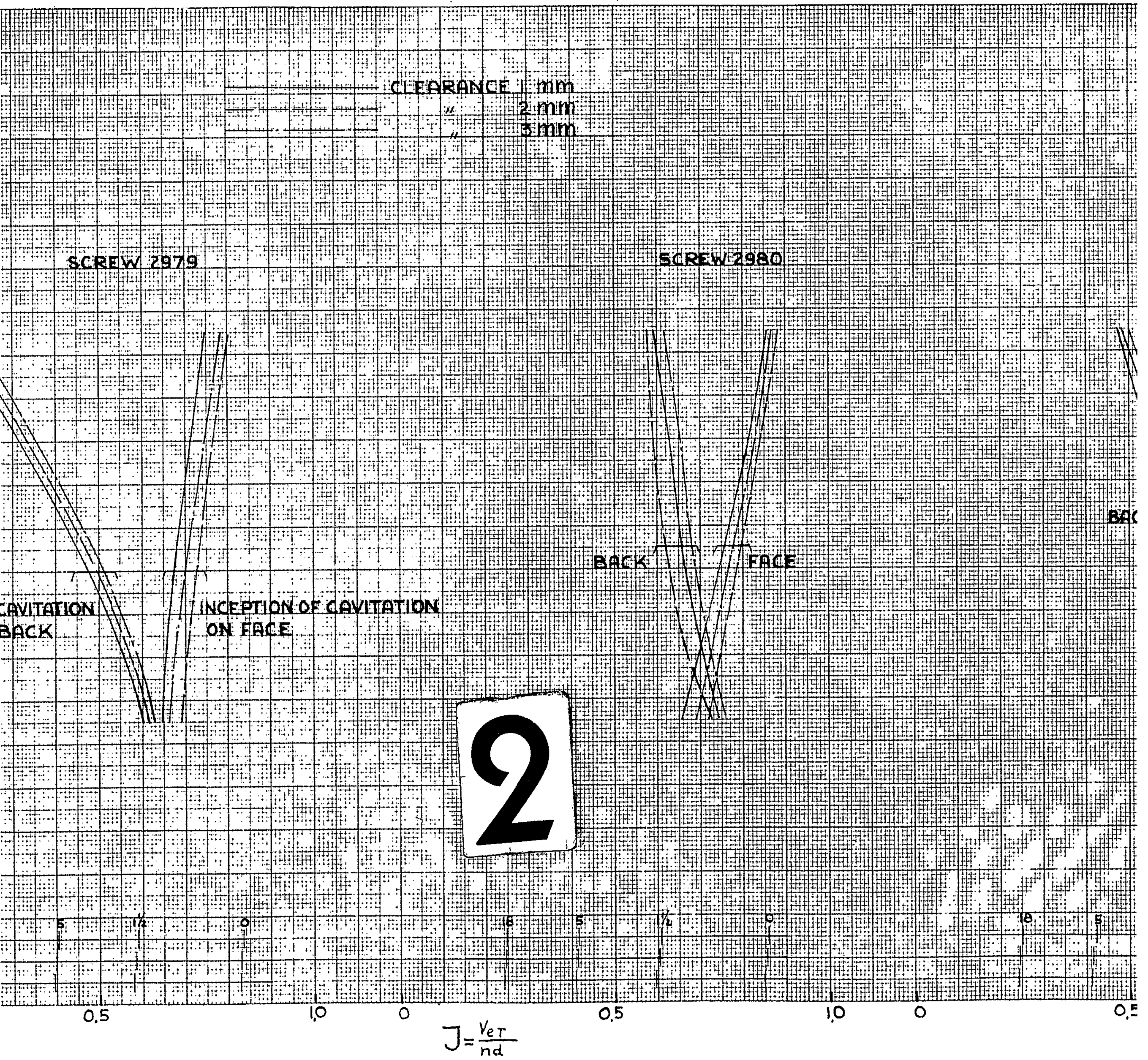
FIG. 13



1
SCREW 2978
SCREW 2979
6.0
5.0
4.0
3.35
2.90
BACK
FACE
INCEPTION OF CAVITATION
ON BACK
ON FACE
18
5
1½
0
0
0.5
1.0

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN

INFLUENCE OF BLADETIP CL
INCEPTION OF BACK AND FACE



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 30

INFLUENCE OF BLADE TIP CLEARANCE ON
INCEPTION OF BACK AND FACE CAVITATION

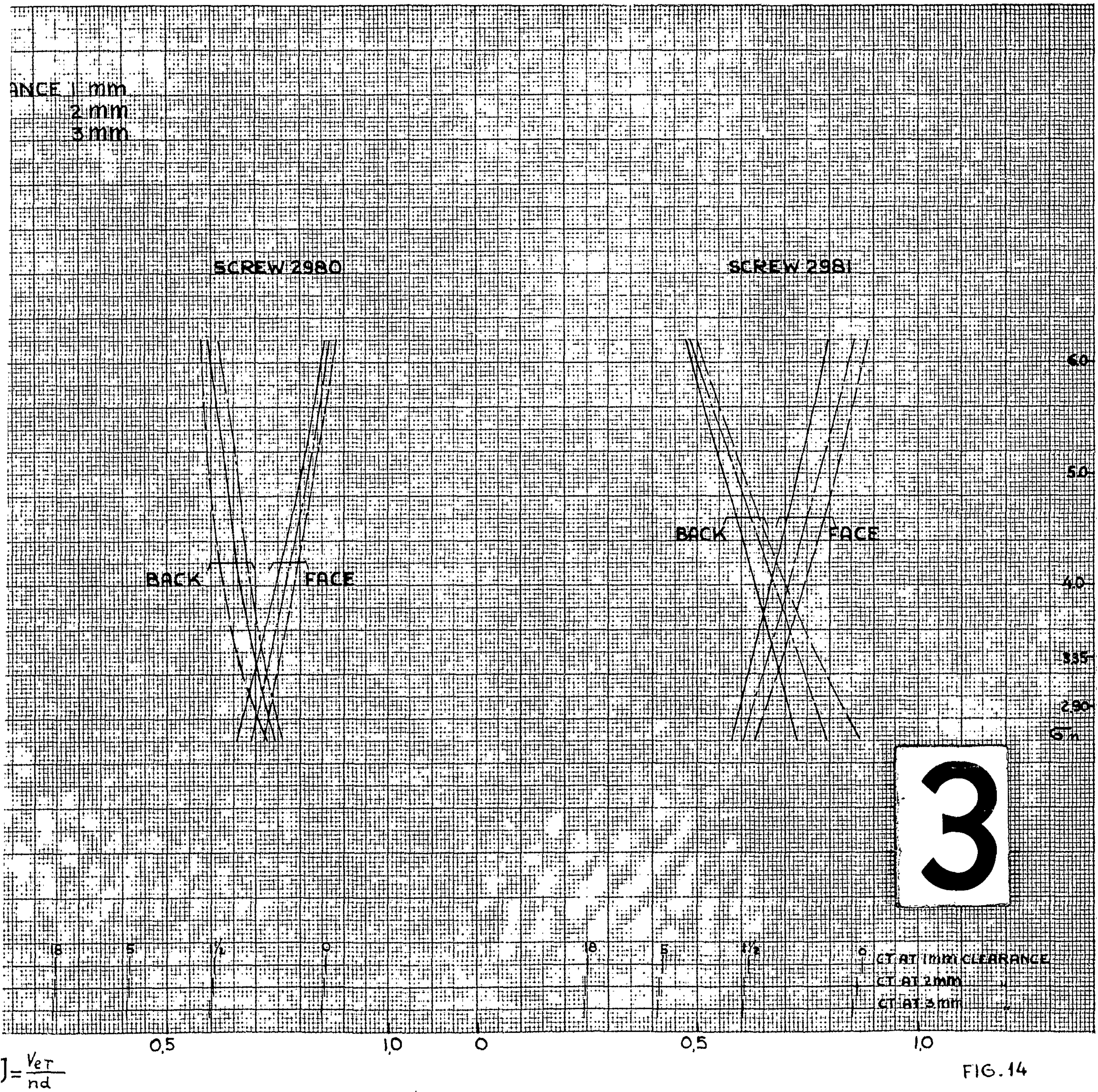
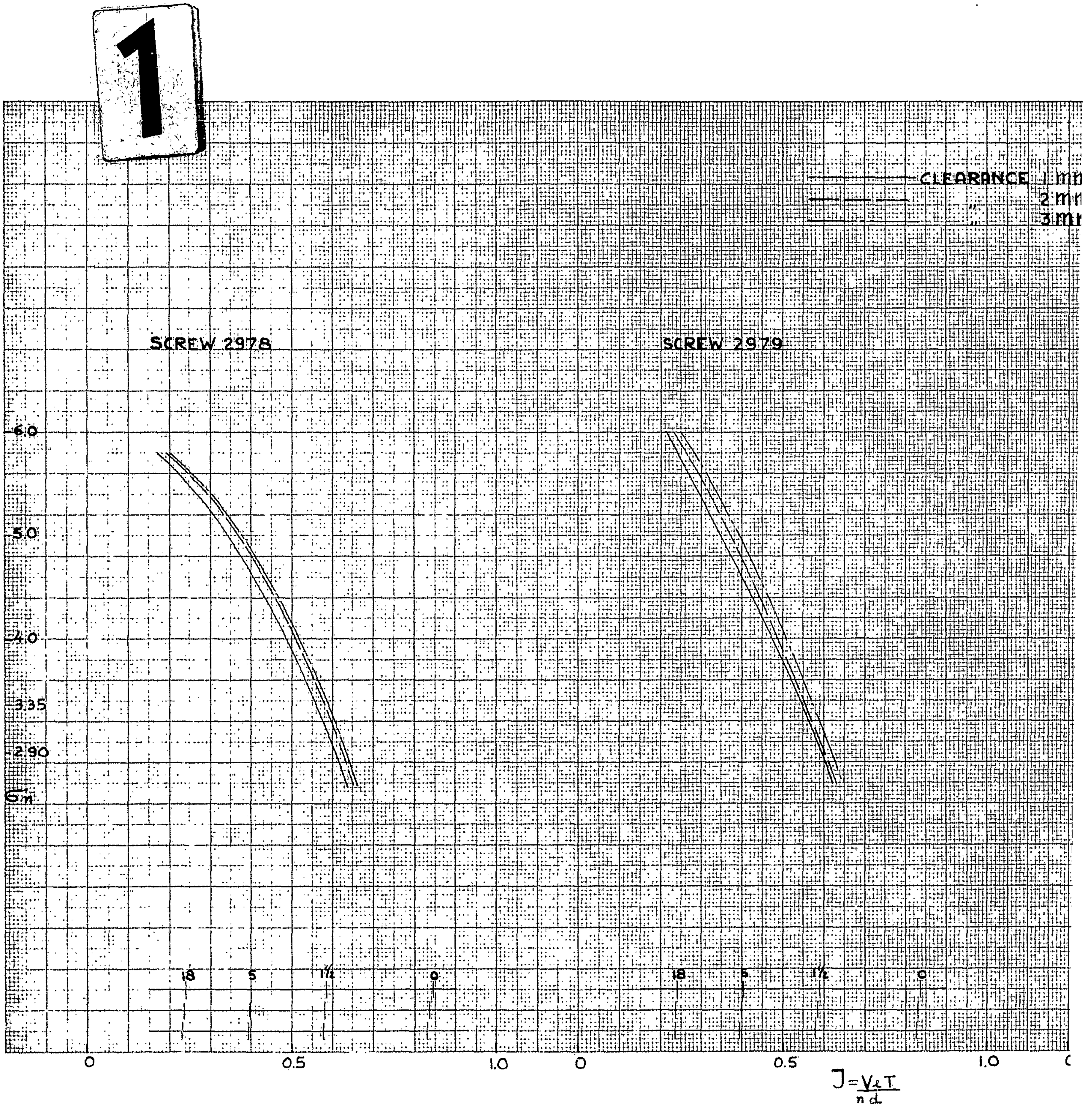
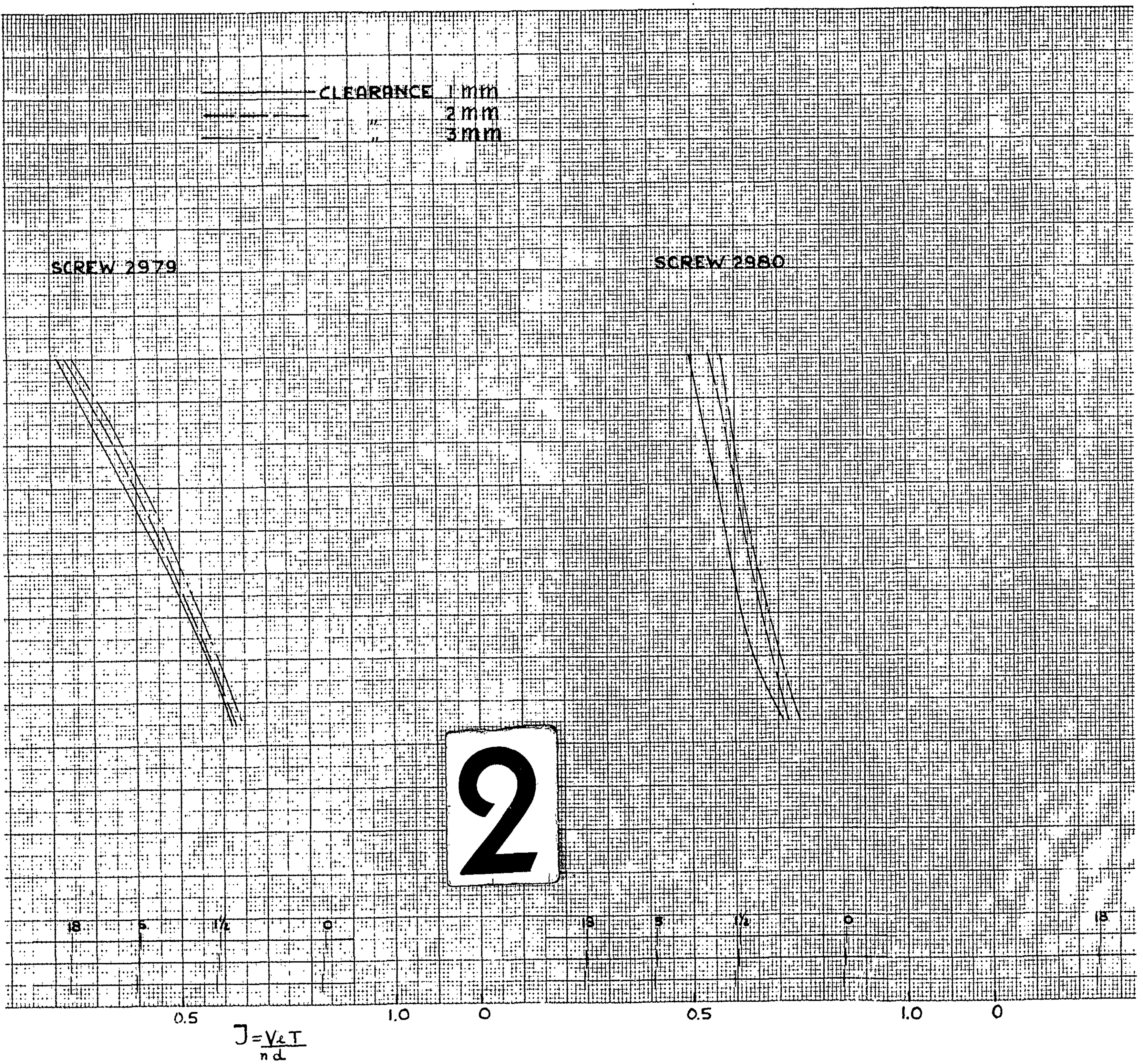


FIG. 14


1
CLEARANCE 1 mm
2 mm
3 mm
SCREW 2978
SCREW 2979
6.0
5.0
4.0
3.35
2.90
18
5
1½
0
0
0.5
1.0
J = $\frac{V_e T}{n d}$

NEDERLANDSCH SCHEEPSBOUWKUNI
PROEFSTATION WAGENING

INFLUENCE OF BLAI
INCEPTION OF



INFLUENCE OF BLADE TIP CLEARANCE ON INCEPTION OF TIP VORTEX CAVITATION

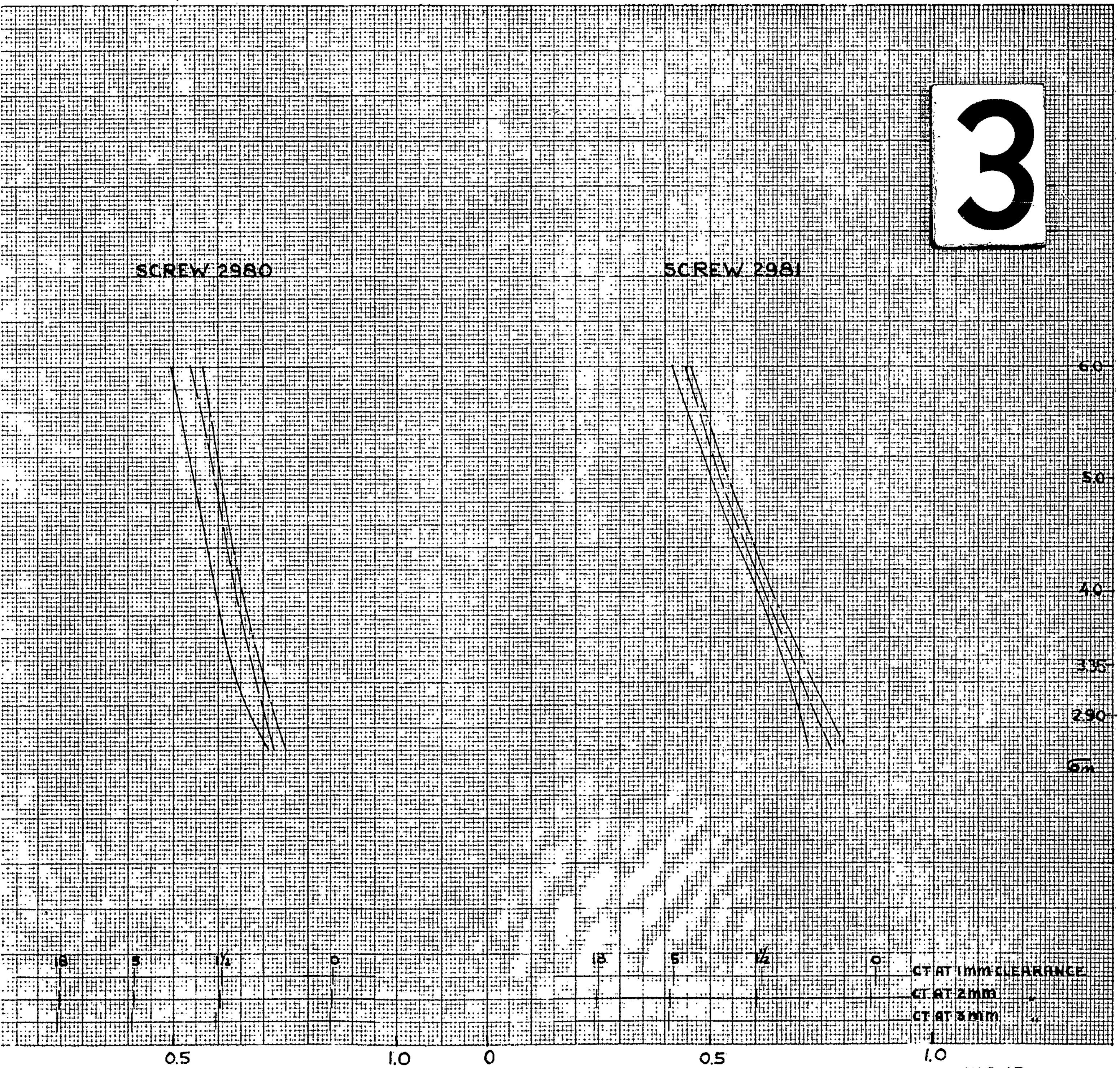
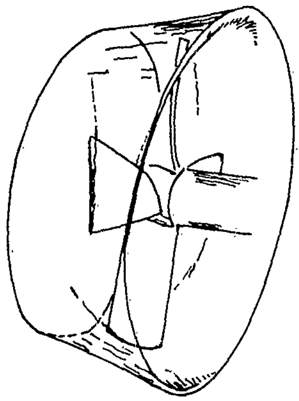


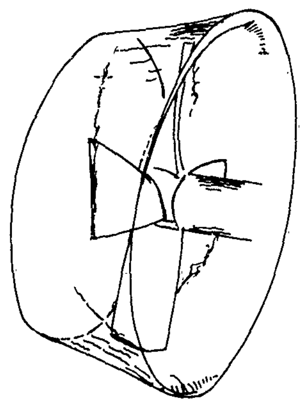
FIG.15

CAVITATION PATTERN AT DESIGN CONDITION

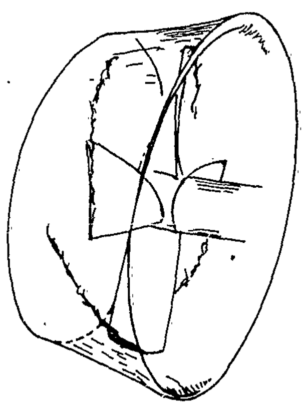
$\sigma_m = 2.31$ $K_{T\ screw} = 0.248$



CLEARANCE 1 mm



CLEARANCE 2 mm



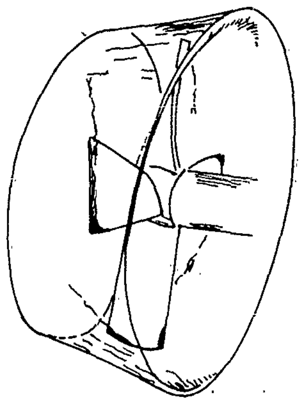
CLEARANCE 3 mm

SCREW 2978

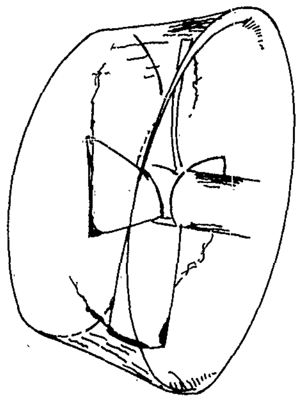
FIG. 16

CAVITATION PATTERN AT DESIGN CONDITION

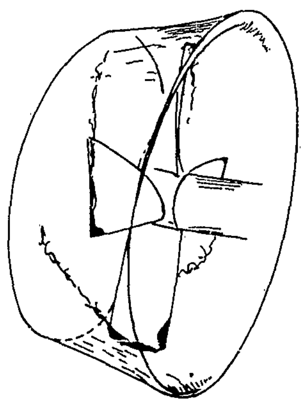
$\sigma_m = 2.31$ K_T SCREW = 0,248



CLEARANCE 1 mm



CLEARANCE 2 mm



CLEARANCE 3 mm

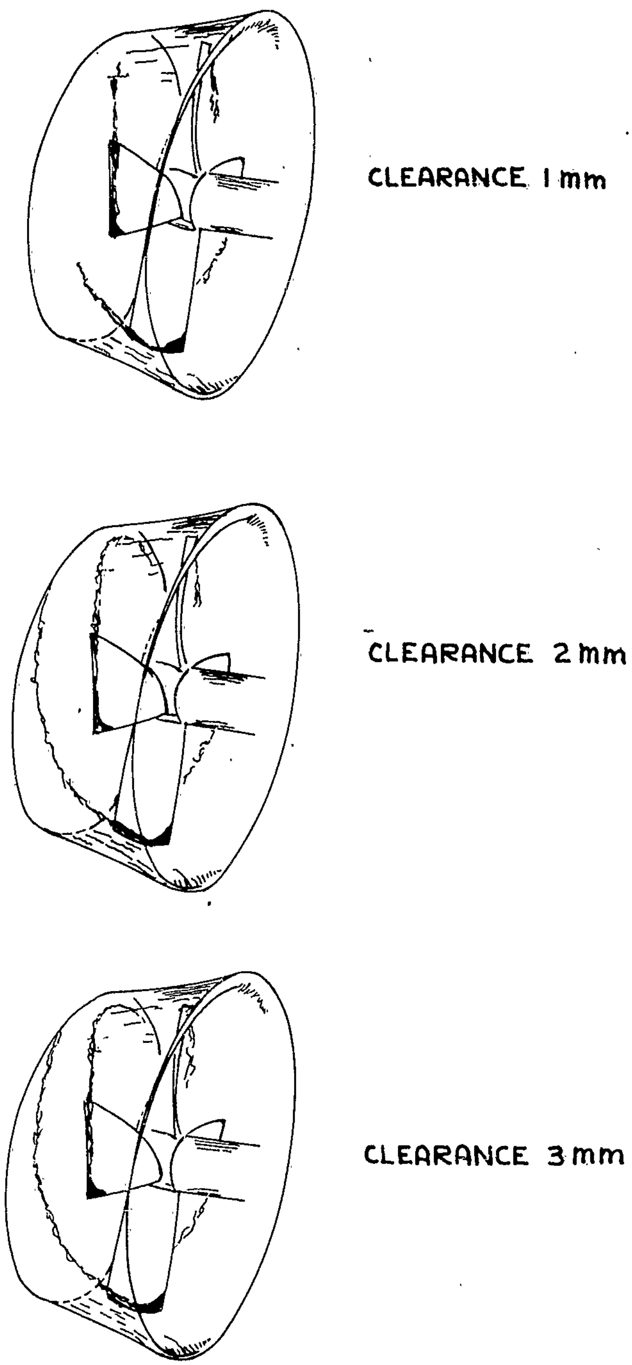
SCREW 2979

FIG. 17

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 34

CAVITATION PATTERN AT DESIGN CONDITION

$\sigma_m = 2.40$ $K_{T\ screw} = 0.258$



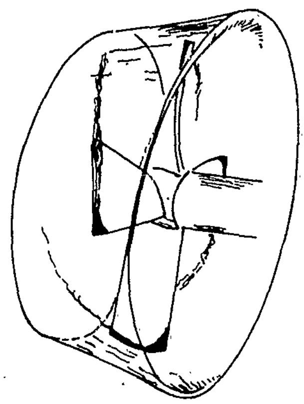
SCREW 2980

FIG. 18

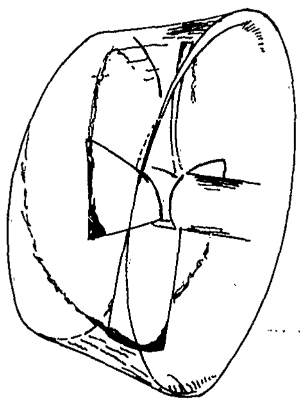
NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 35

CAVITATION PATTERN AT DESIGN CONDITION

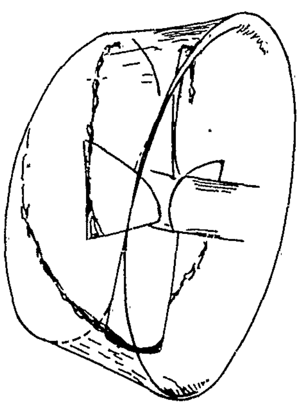
$\sigma_m = 2.44$ K_T SCREW $= 0.262$



CLEARANCE 1 mm



CLEARANCE 2 mm

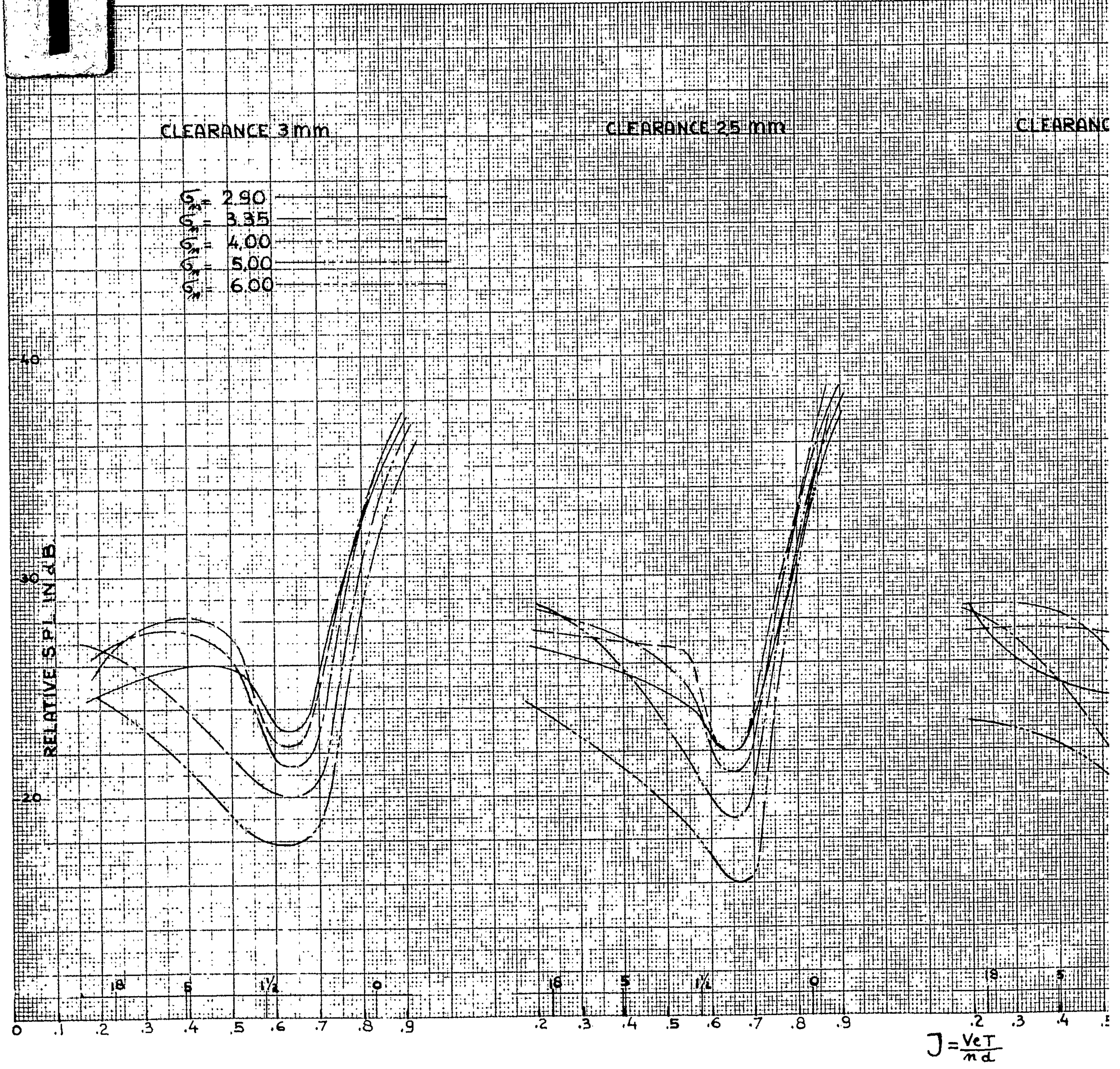


CLEARANCE 3 mm

SCREW 2981

FIG. 19

1



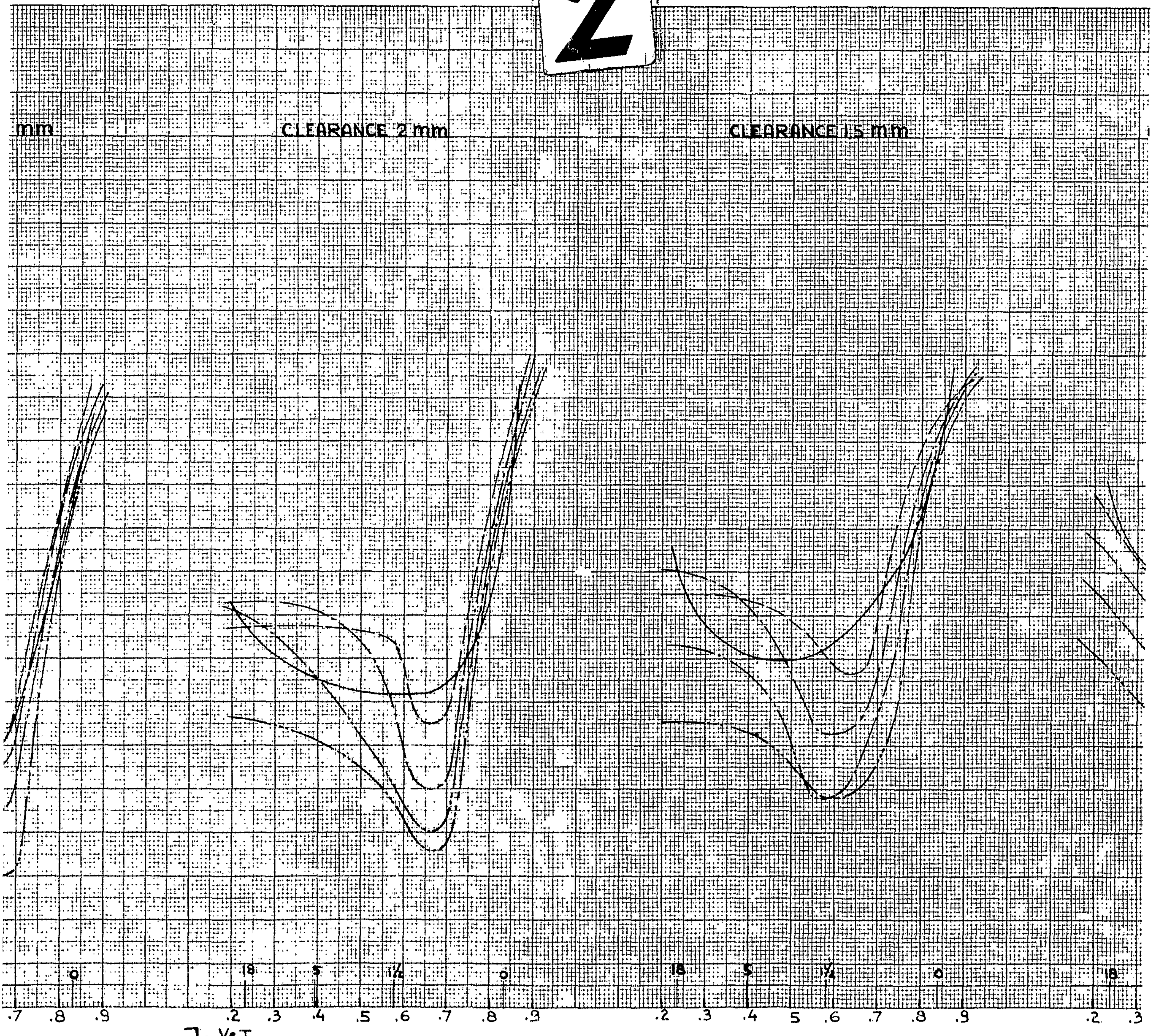
CLEARANCE 3 mm
CLEARANCE 2.5 mm
CLEARANC
σ = 2.90
σ = 3.35
σ = 4.00
σ = 5.00
σ = 6.00
RELATIVE S.P.L IN dB
40
30
20
18
5
1½
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
J = VeT / nd

NEDERLANDSCH SCHEEPSBOUWKUNDIG
PROEFSTATION WAGENINGEN

C

2

RELATION BETWEEN BLADETIP
NUMBER AND PROPELLER
SCREW 2978



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 36

RELATION BETWEEN BLADE TIP CLEARANCE, CAVITATION NUMBER AND PROPELLER NOISE

SCREW 2978

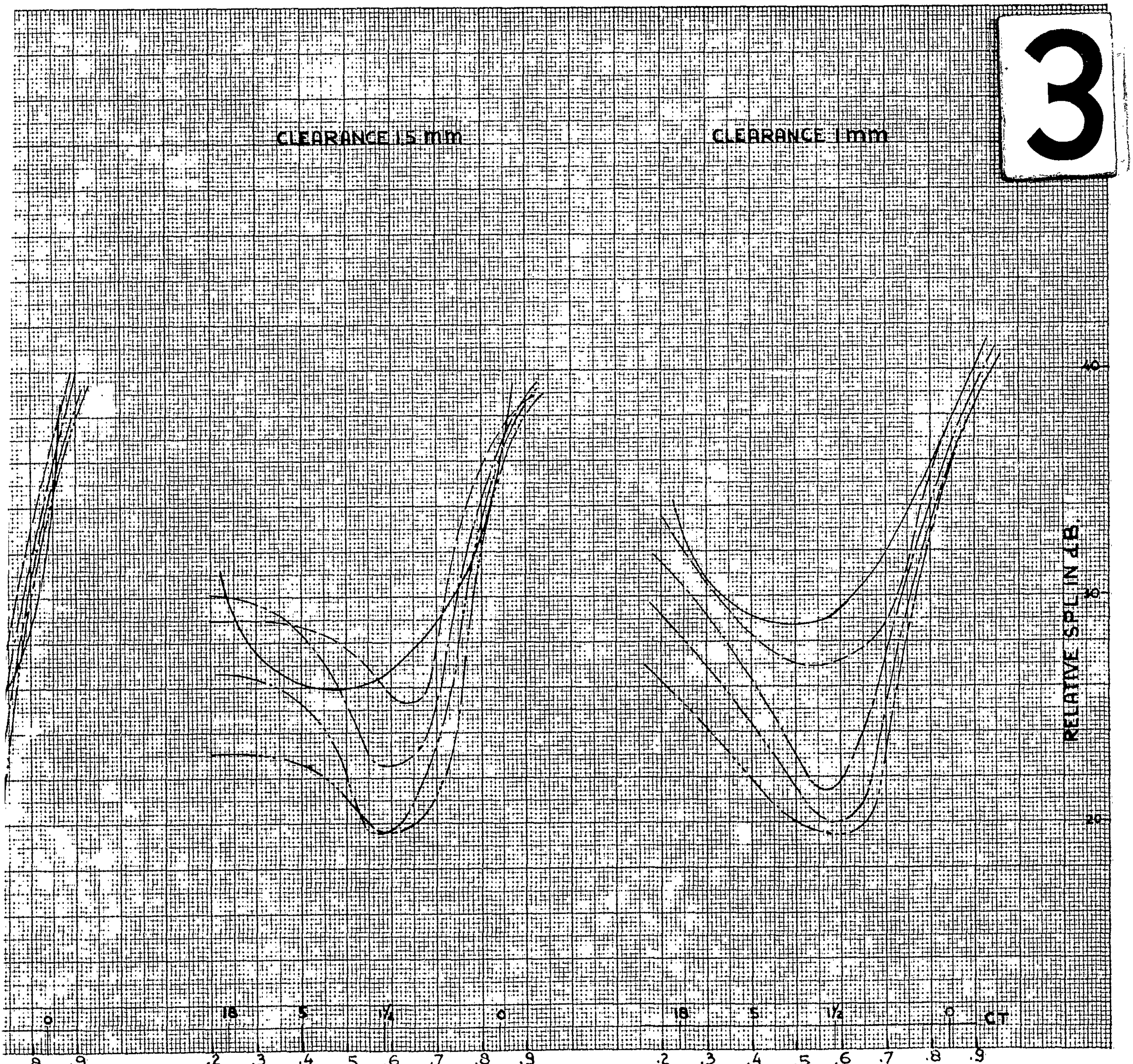
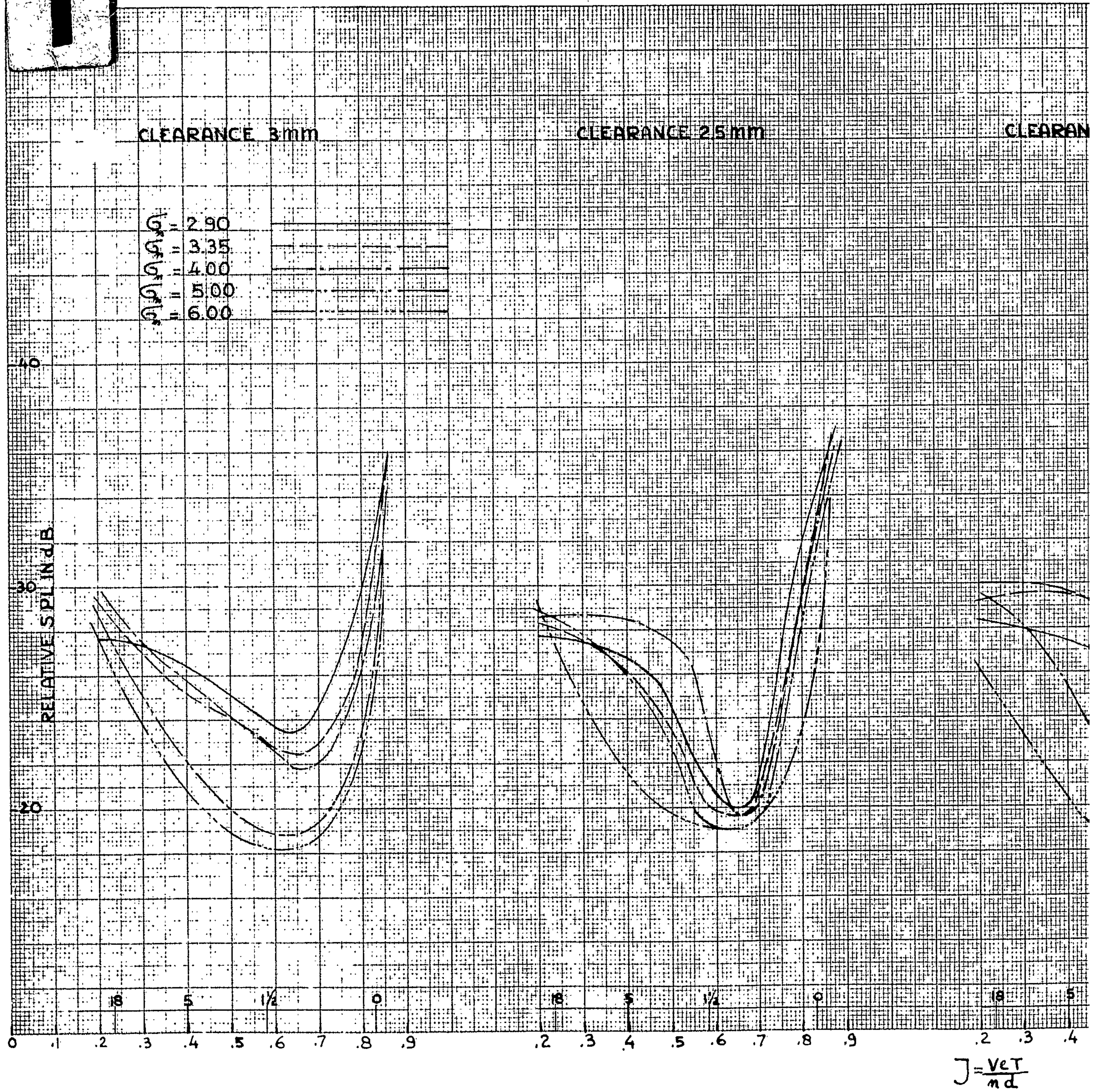


FIG. 20

1

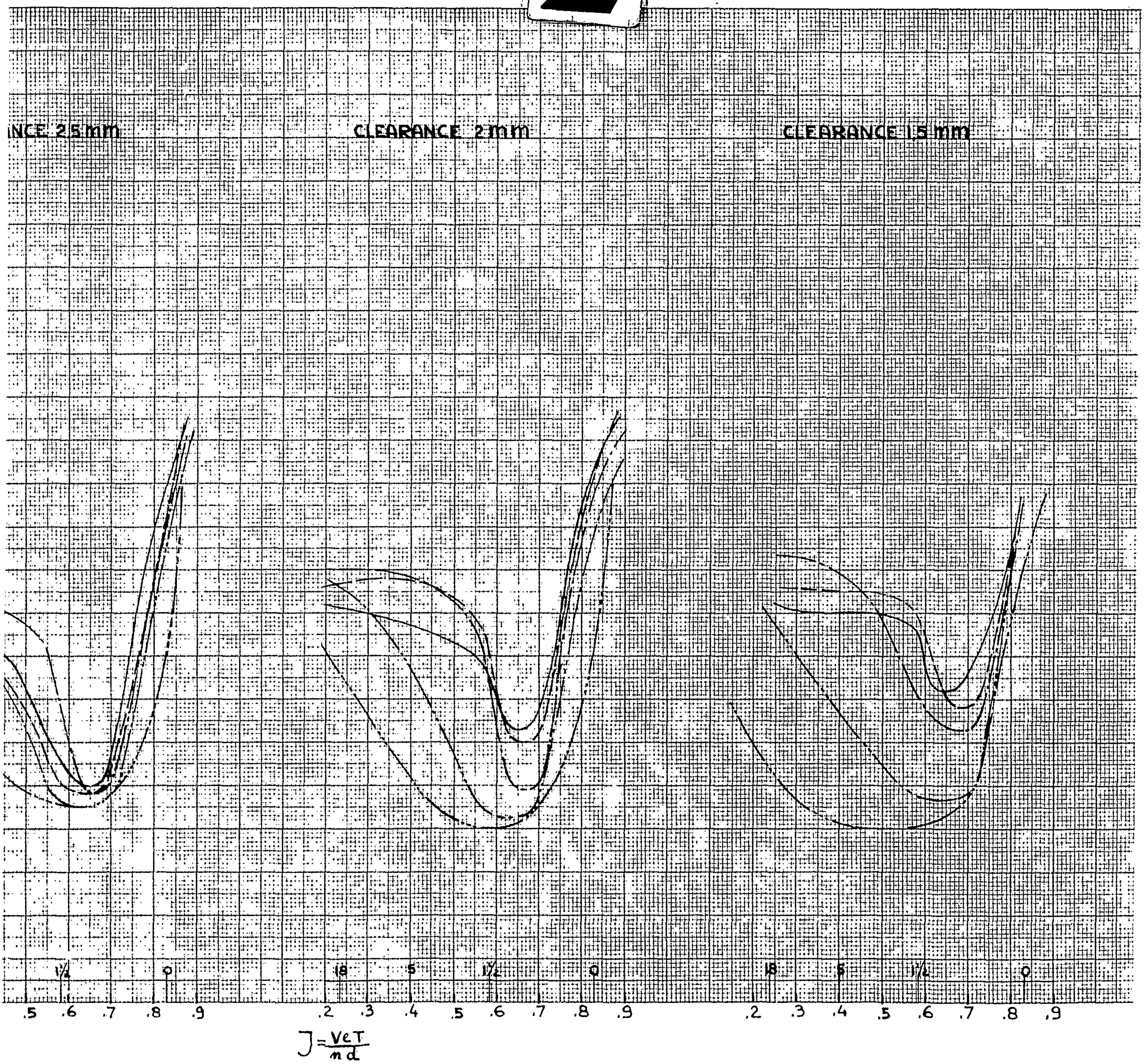


CLEARANCE 3mm
CLEARANCE 2.5mm
CLEARAN
σ_s = 2.90
σ_s = 3.35
σ_s = 4.00
σ_s = 5.00
σ_s = 6.00
RELATIVE SPL IN dB
40
30
20
18
5
1½
0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9
.2 .3 .4 .5 .6 .7 .8 .9
.2 .3 .4
$J = \frac{VeT}{nd}$

NEDERLANDSCH SCHEEPSBOUWKU
PROEFSTATION WAGENI

2

RELATION BETWEE
NUMBER AN
S



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 37

RELATION BETWEEN BLADE TIP CLEARANCE, CAVITATION NUMBER AND PROPELLER NOISE

SCREW 2979

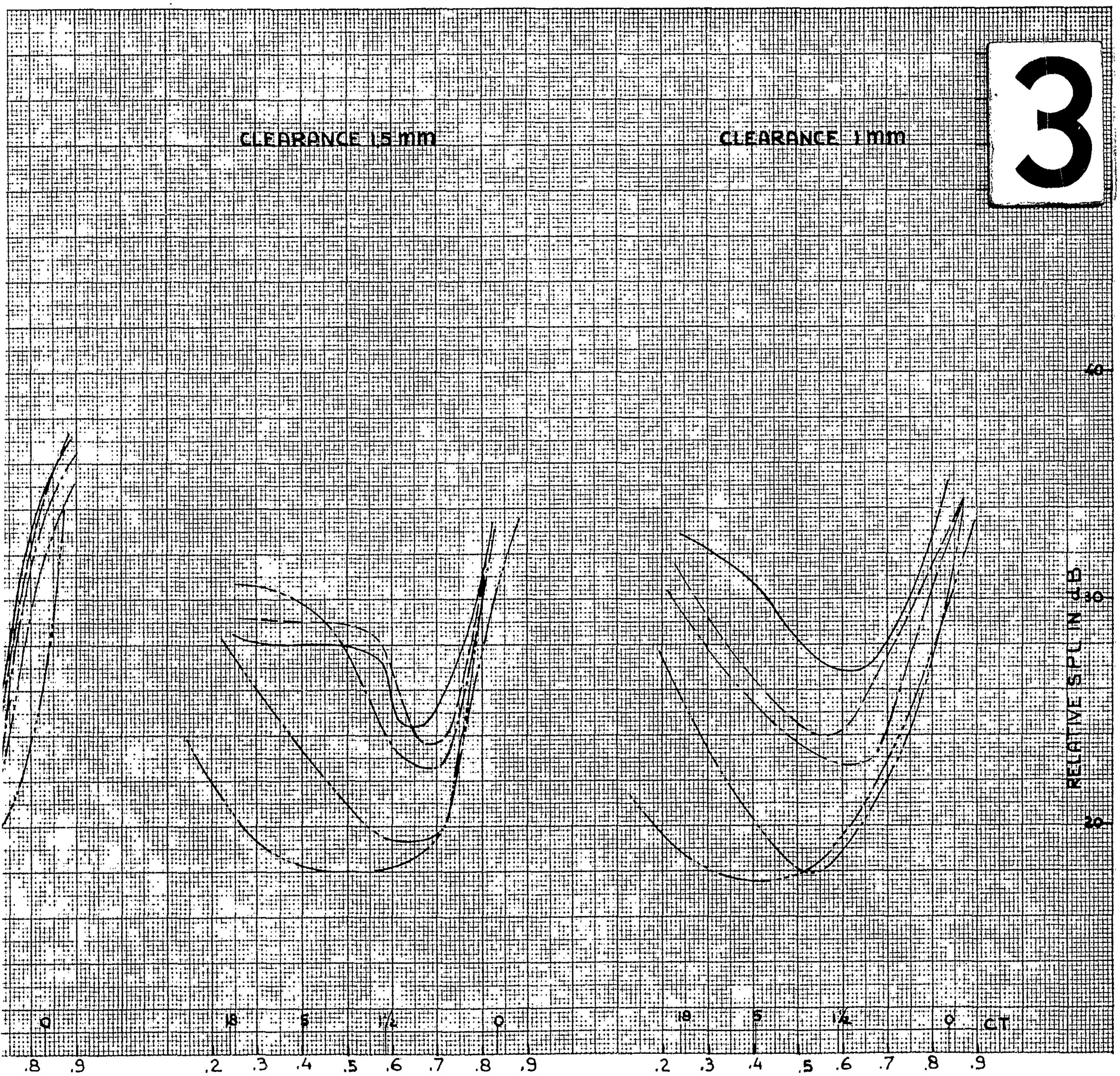
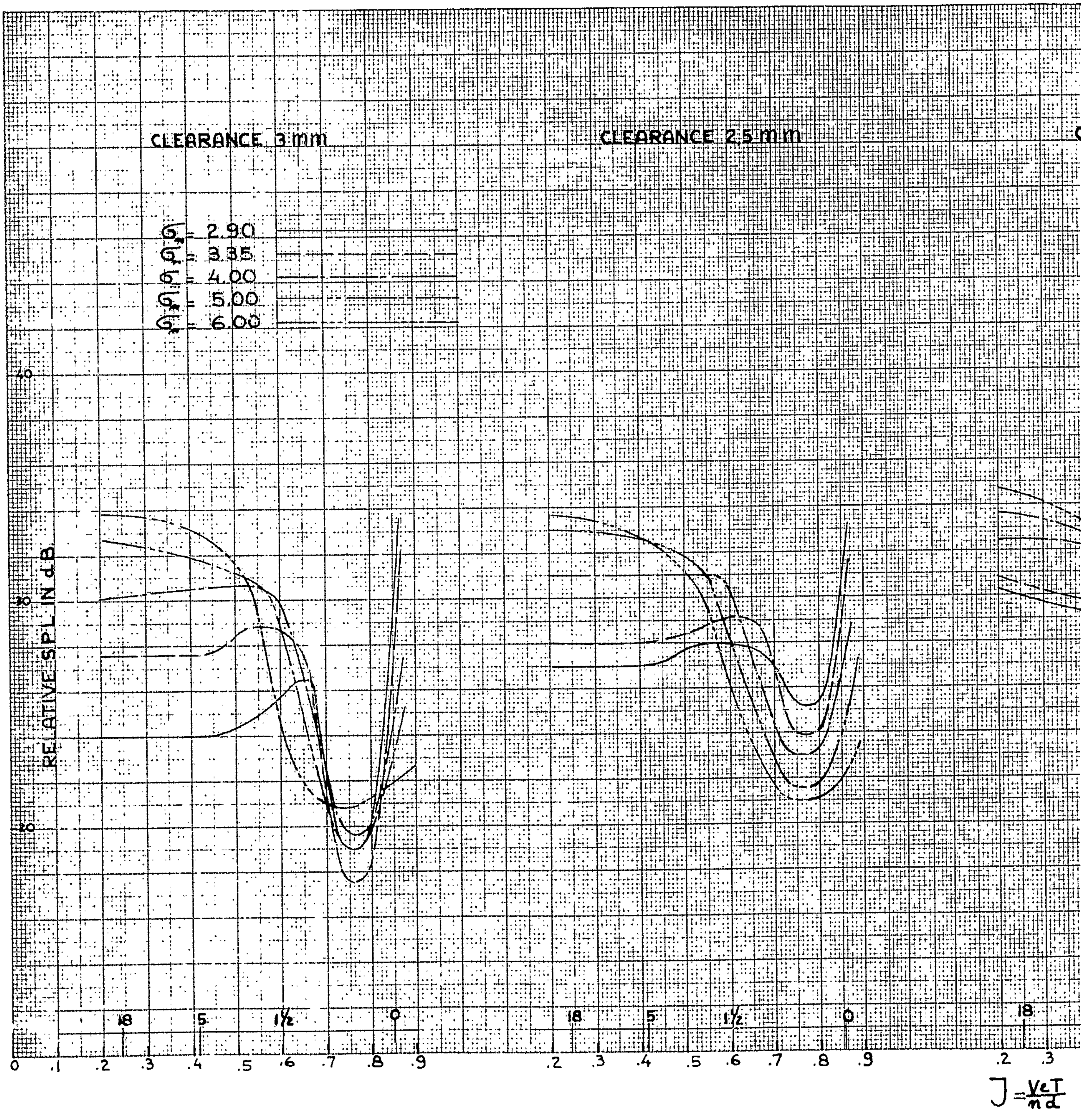


FIG. 21

1

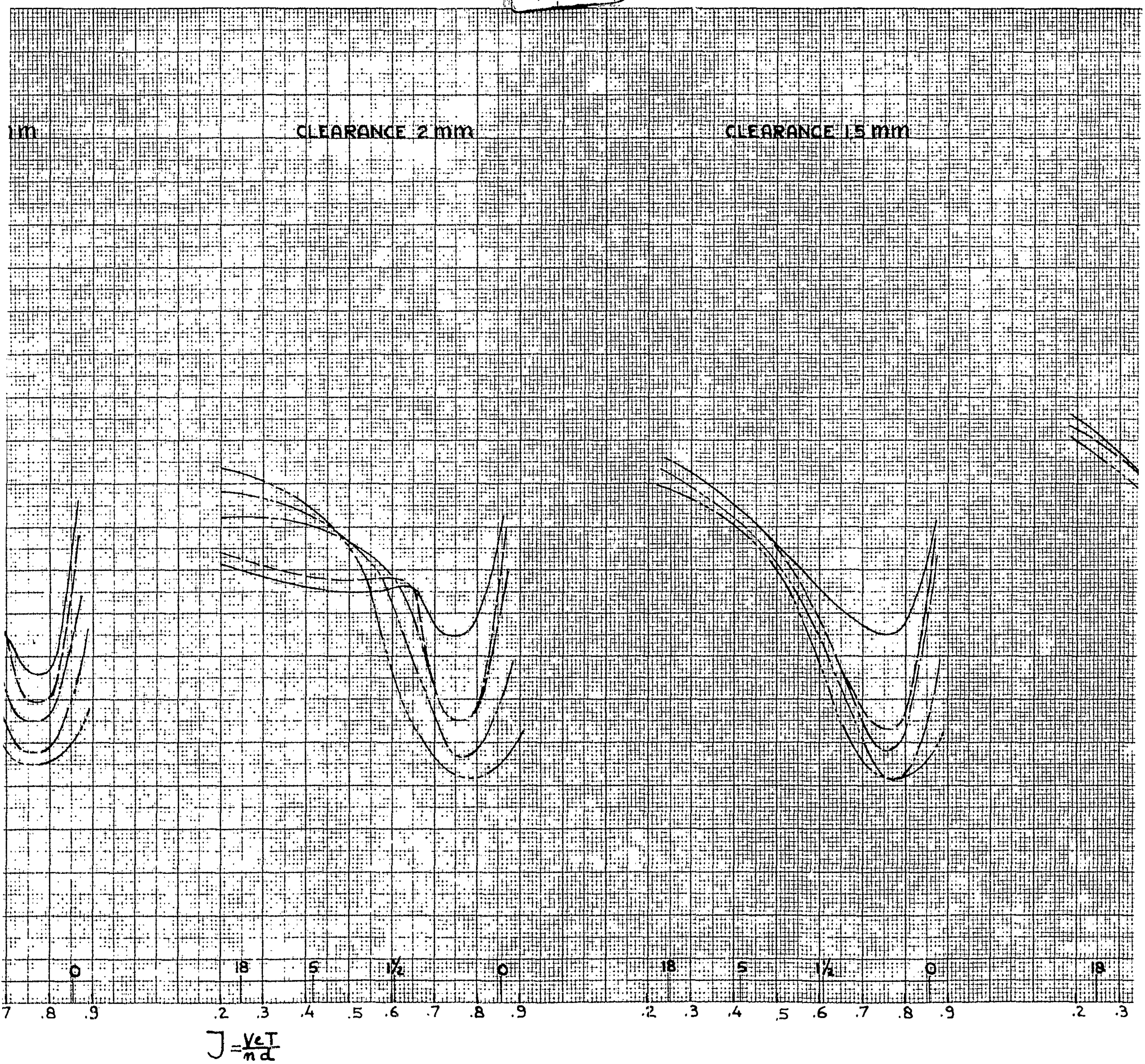


CLEARANCE 3 mm
CLEARANCE 2.5 mm
σ = 2.90
σ = 3.35
σ = 4.00
σ = 5.00
σ = 6.00
RELATIVE SPL IN dB
40
30
20
18
5
1½
0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9
.2 .3 .4 .5 .6 .7 .8 .9
.2 .3
J = VeT/nd

2

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CA

RELATION BETWEEN BLADE T
NUMBER AND PROP
SCREW 29



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT No. 535	BLZ. 38

RELATION BETWEEN BLADE TIP CLEARANCE, CAVITATION NUMBER AND PROPELLER NOISE

SCREW 2980

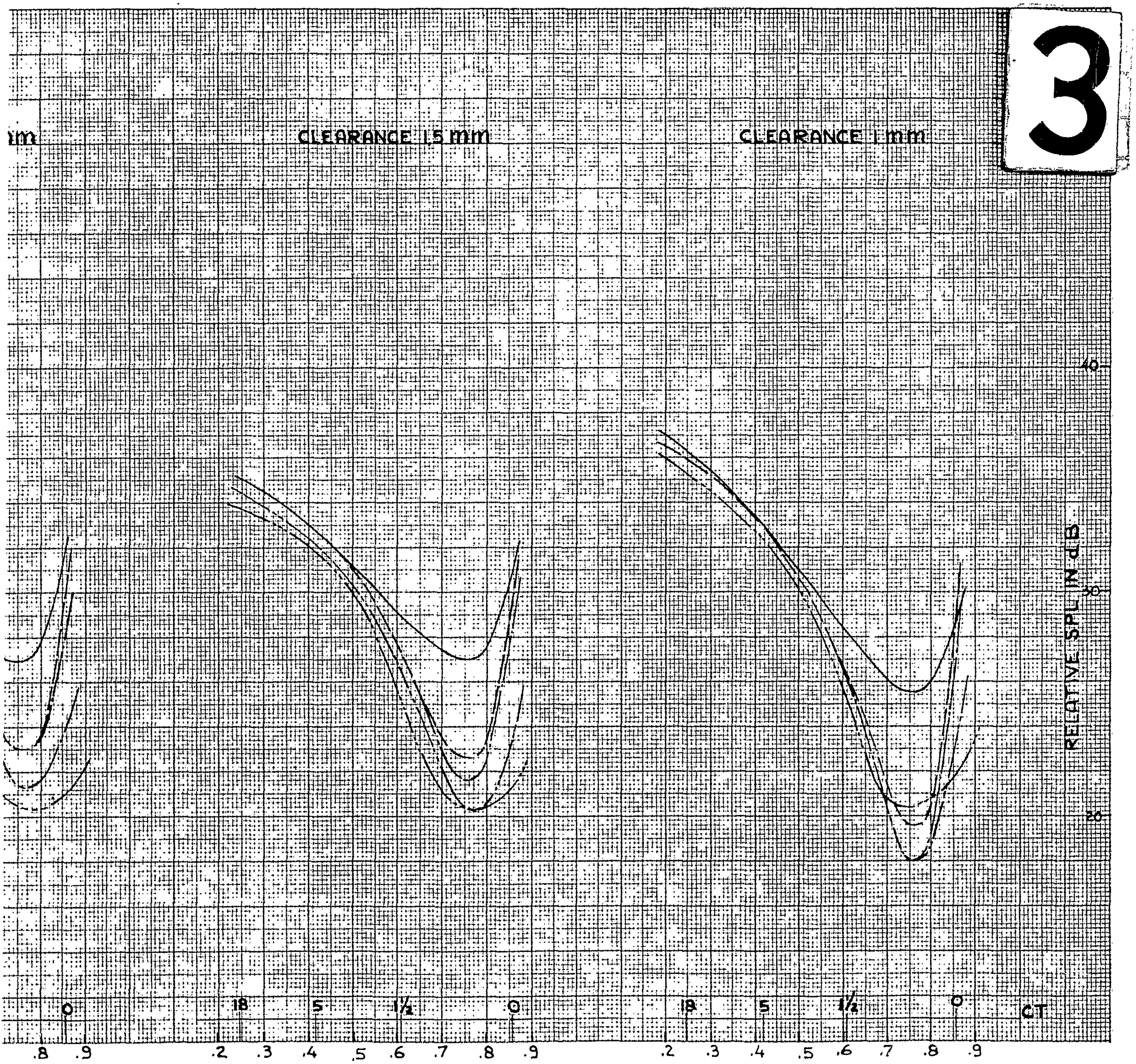
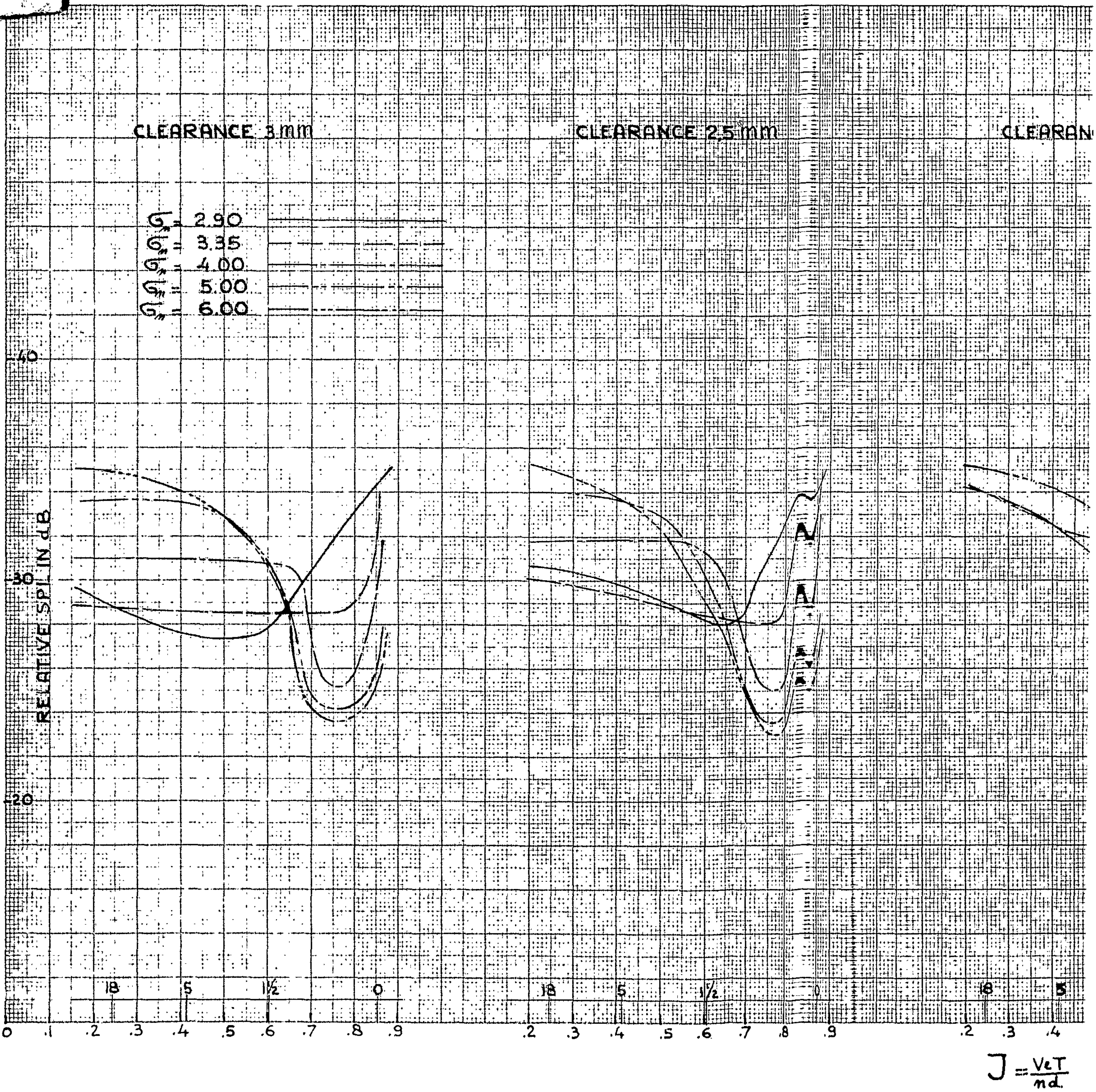


FIG. 22

1

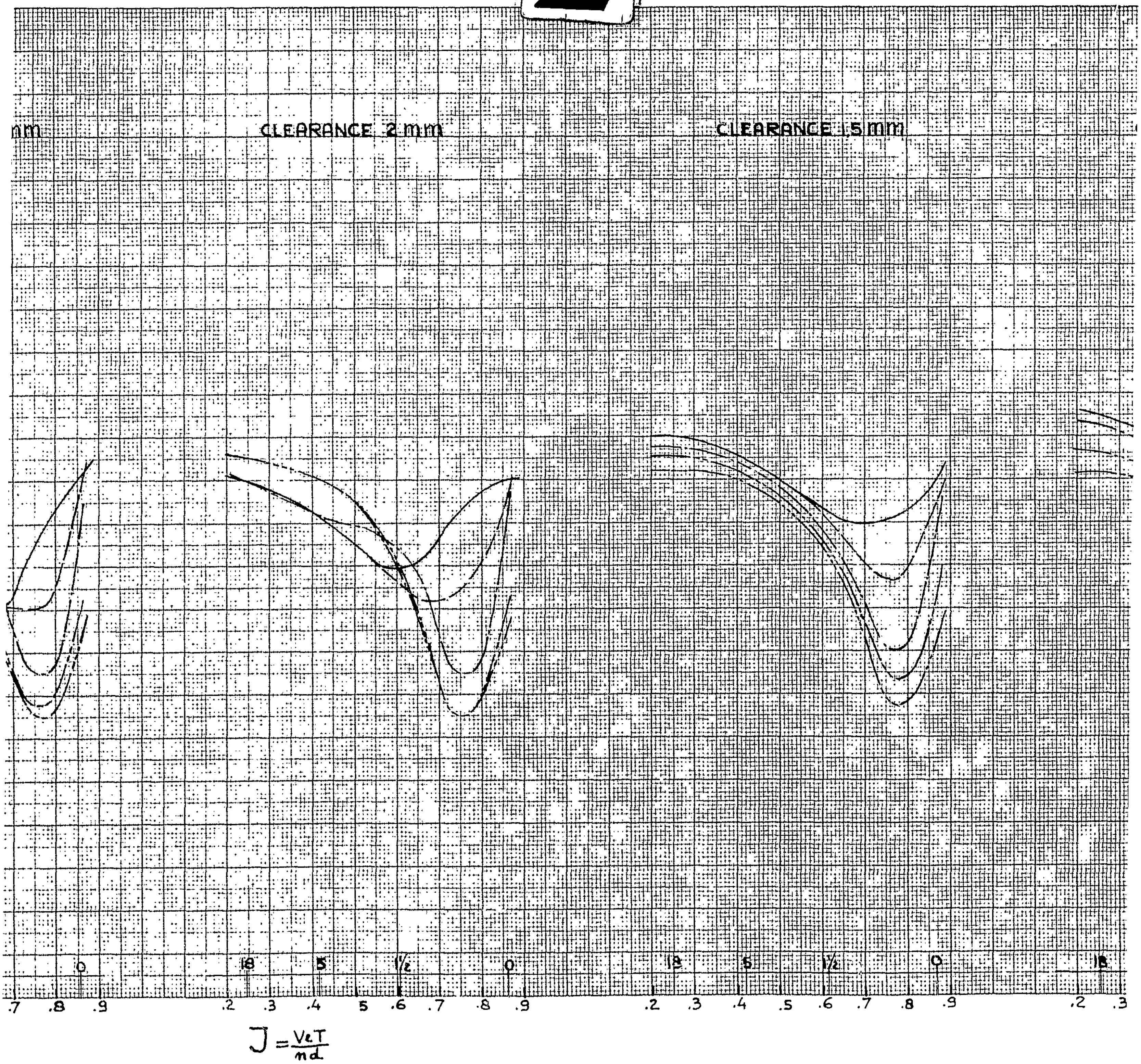


CLEARANCE 3 mm
CLEARANCE 2.5 mm
CLEARAN
σ_m = 2.90
σ_m = 3.35
σ_m = 4.00
σ_m = 5.00
σ_m = 6.00
RELATIVE SPL IN dB
40
30
20
18
5
1½
0
0 .1 .2 .3 .4 .5 .6 .7 .8 .9
.2 .3 .4 .5 .6 .7 .8 .9
.2 .3 .4
$J = \frac{V_e T}{nd}$

NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN

RELATION BETWEEN BLADE
NUMBER AND PROF
SCREW 2

2



NEDERLANDSCH SCHEEPSBOUWKUNDIG PROEFSTATION WAGENINGEN	CAVITATION TEST REPORT NO. 535	BLZ. 39

RELATION BETWEEN BLADE TIP CLEARANCE, CAVITATION NUMBER AND PROPELLER NOISE

SCREW 2981

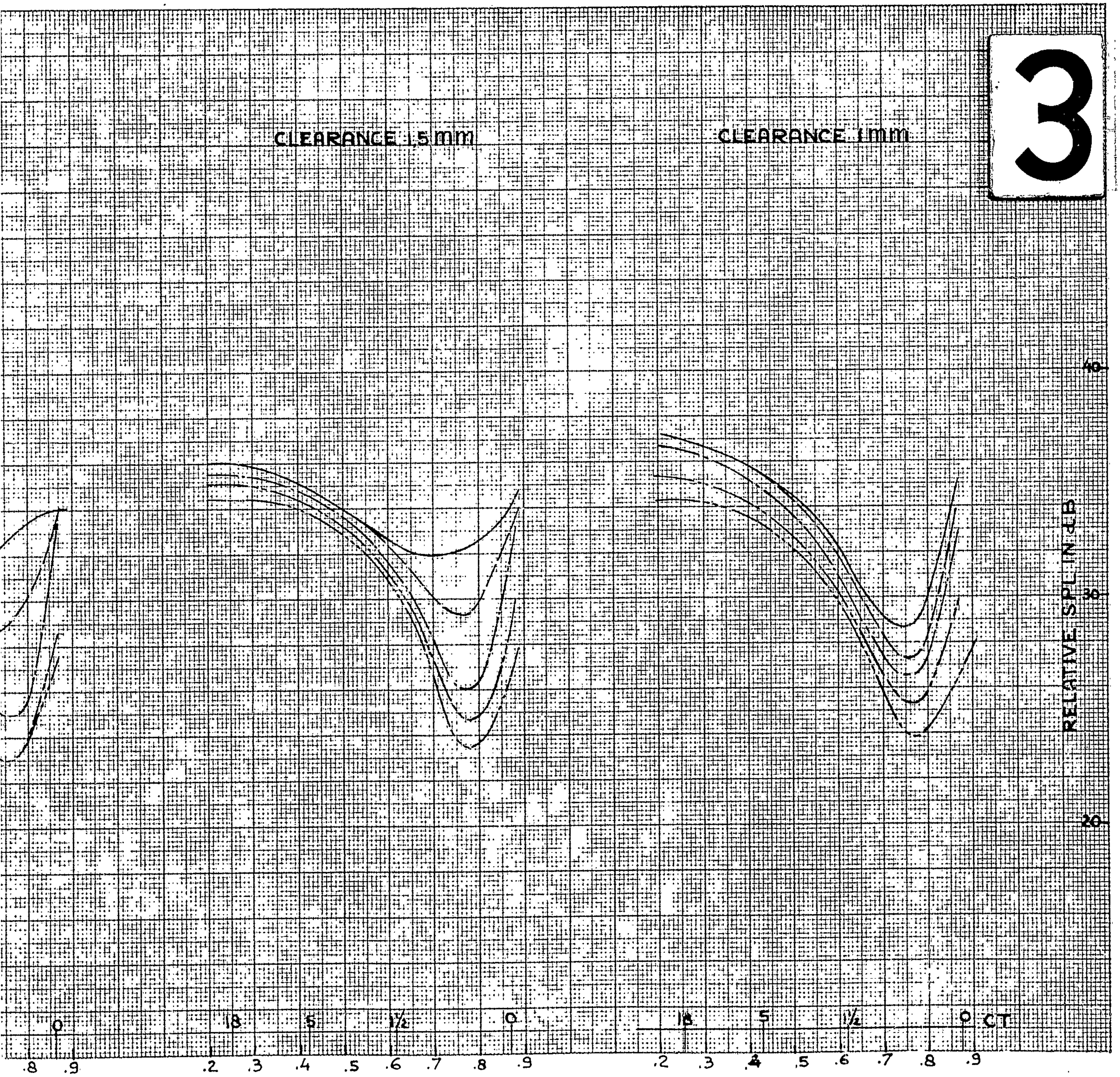
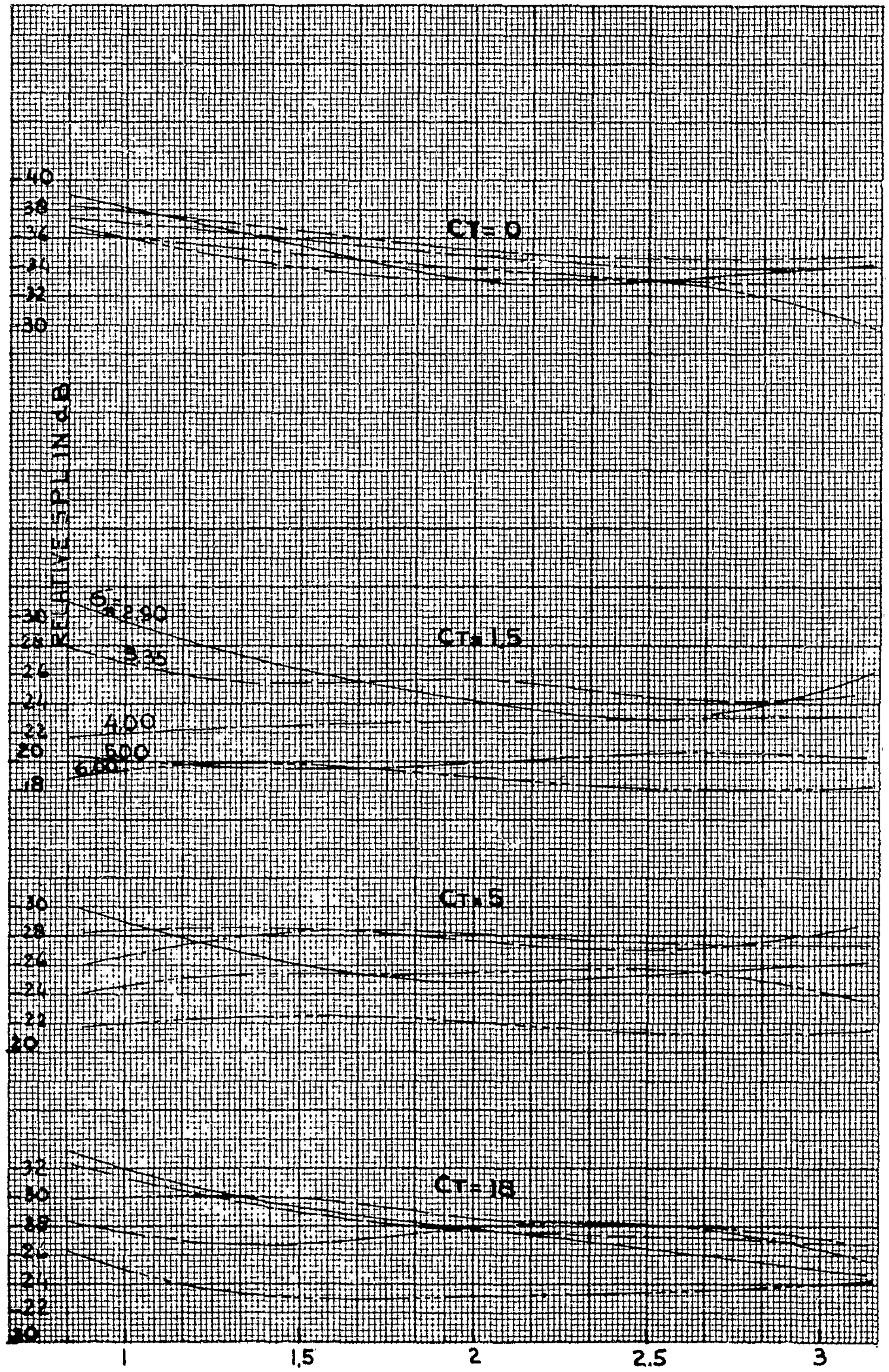


FIG. 23

INFLUENCE OF BLADE TIP CLEARANCE AND CAVITATION NUMBER ON NOISE PRODUCTION

SCREW 2978



CLEARANCE IN mm

FIG. 24

INFLUENCE OF BLADE TIP CLEARANCE AND CAVITATION NUMBER ON NOISE PRODUCTION

SCREW 2979

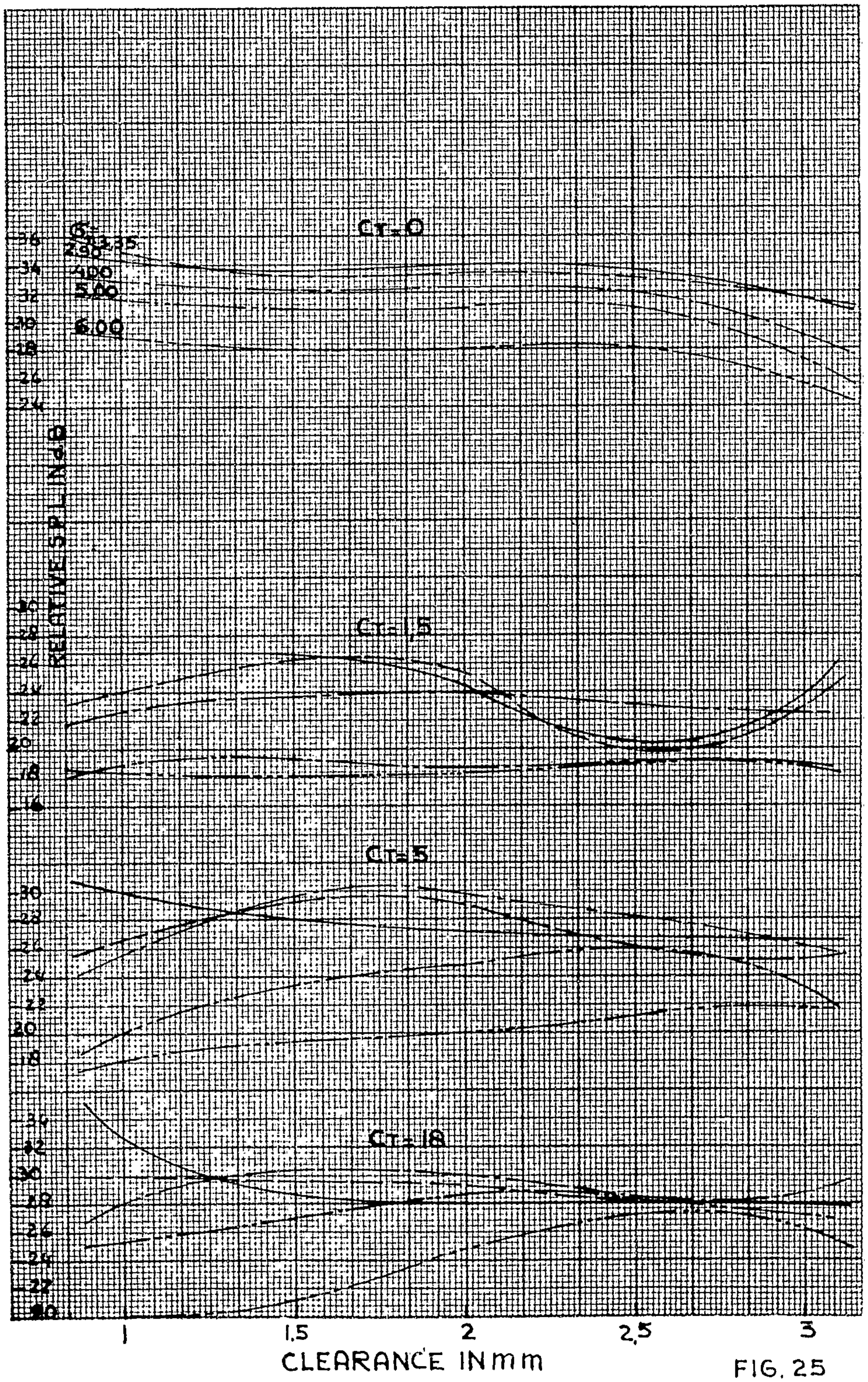


FIG. 25

INFLUENCE OF BLADETIP CLEARANCE AND CAVITATION NUMBER ON NOISE PRODUCTION

SCREW 2980

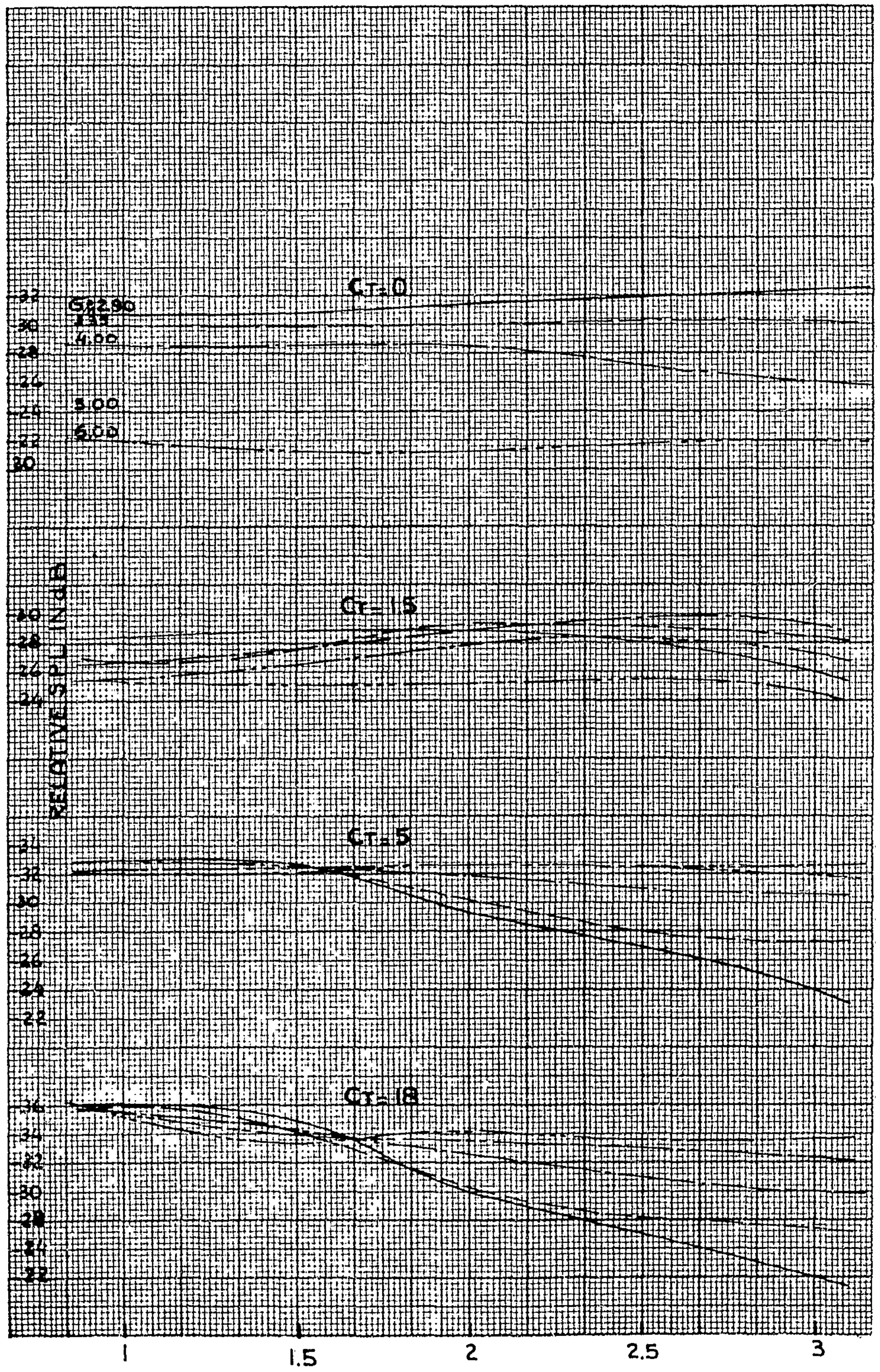


FIG. 26

INFLUENCE OF BLADE TIP CLEARANCE AND CAVITATION NUMBER ON NOISE PRODUCTION

SCREW 2981.

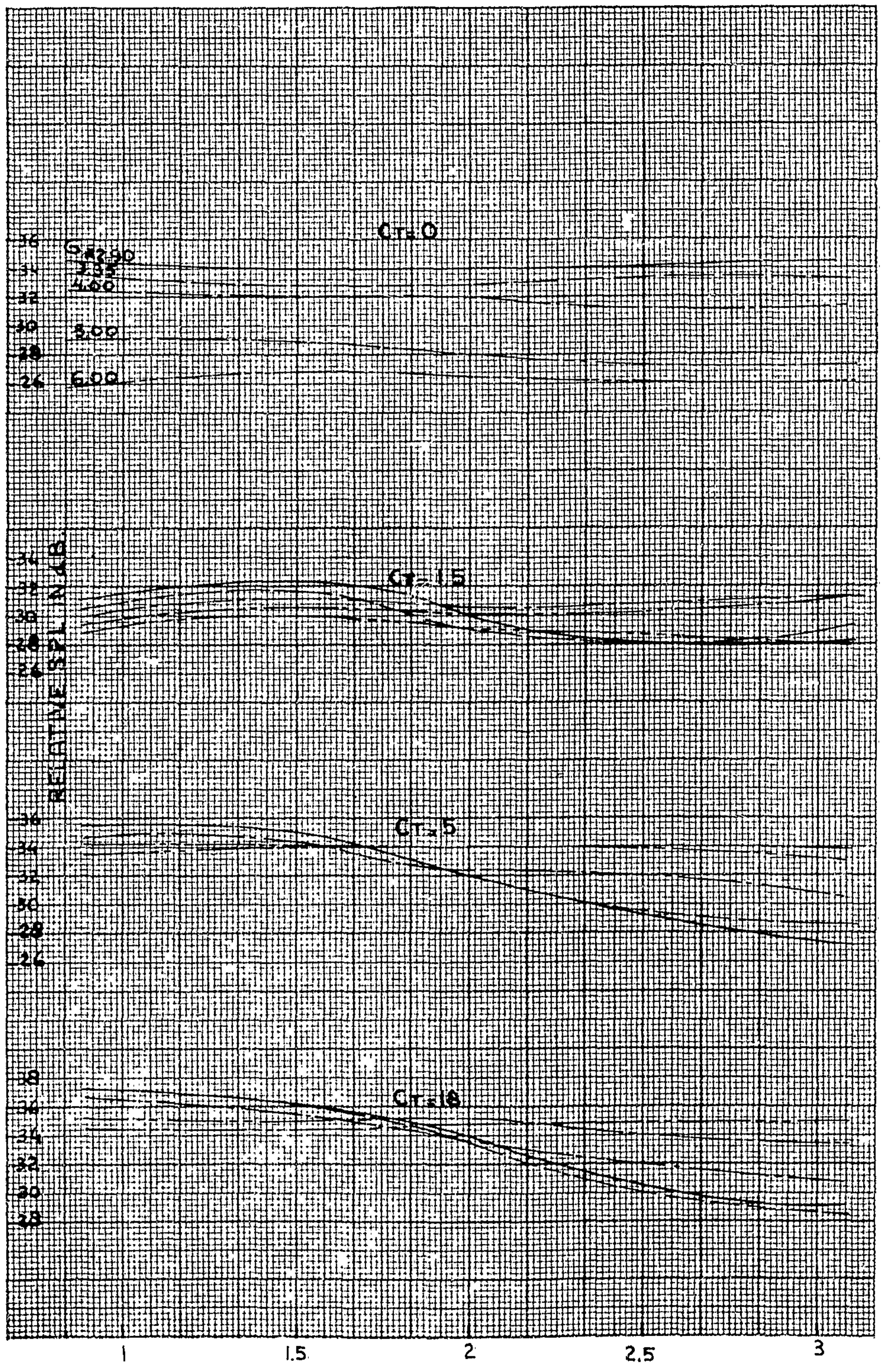
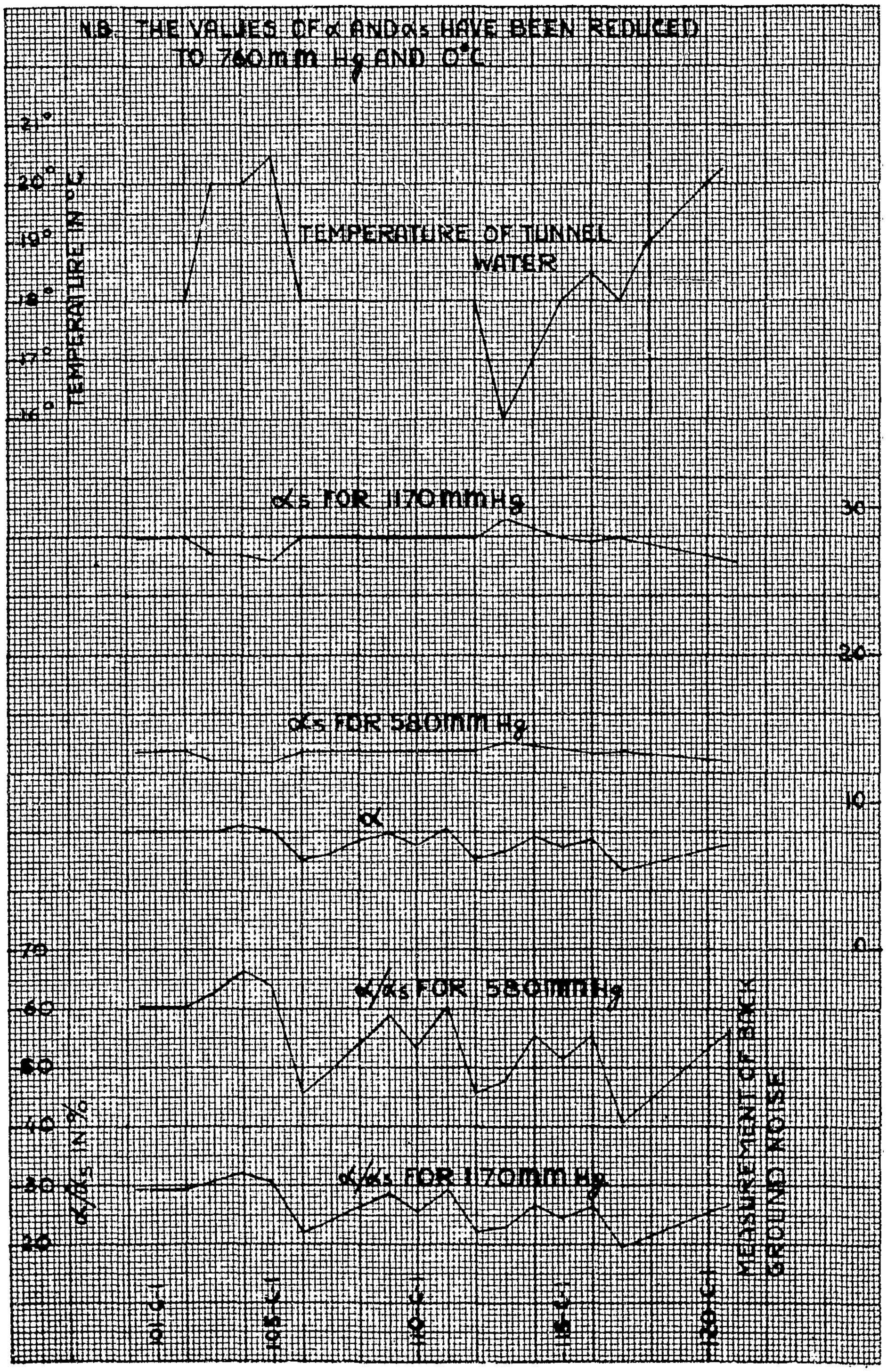


FIG. 27

TIME HISTORY OF AIR CONTENT



TEST № →

FIG. 28